U.S. Chemical Safety and Hazard Investigation Board

Fatal Runaway Reaction and Explosion at Givaudan Sense Colour / D.D. Williamson

Louisville, Kentucky | *Incident Date: November 12, 2024* | **No. 2024-06-I-KY**

Investigation Report

Published: May 2026

SAFETY ISSUES:

- Understanding Chemical Reaction Hazards
- Commitment to Managing Process Safety
- Safe Operating Limits
- Facility Siting
- Regulatory Coverage of Reactive Hazards

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The November 12, 2024, explosion at the Givaudan facility in Louisville, Kentucky, fatally injured two people:

Kevens Dawson, Jr

Austin Jaggers

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ABBREVIATIONS

ASME	American Society of Mechanical Engineers
APTAC	Automatic Pressure Tracking Adiabatic Calorimetry
ARC	Accelerating Rate Calorimetry
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
EPA	U.S. Environmental Protection Agency
HAZOP	Hazard and Operability Study
HMF	5-hydroxymethylfurfural
ITCA	International Technical Caramel Association
MAWP	Maximum Allowable Working Pressure
MAWT	Maximum Allowable Working Temperature
MOC	Management of Change
OSHA	Occupational Safety and Health Administration
PLC	Programmable Logic Controller
PHA	Process Hazard Analysis
PRV	Pressure Relief Valve
psig	Pounds per square inch gauge
PSM	Process Safety Management
RMP	Risk Management Program
SDS	Safety Data Sheet

EXECUTIVE SUMMARY

On November 12, 2024, a batch reactor vessel ("Reactor 6") exploded at the Givaudan Sense Colour ("Givaudan") caramel coloring manufacturing facility ("Louisville facility") in Louisville, Kentucky, while it was producing caramel coloring for a food product. The explosion fatally injured two employees, and seriously injured three others. The explosion occurred during the manufacturing operation of Product 484, a caramel coloring product, which was routinely manufactured at the Louisville facility.

Reactor 6 was constructed in 1978 and was originally operated at a D.D. Williamson facility in Modesto, California, which shut down in 2008. After the closure of the Modesto facility, Reactor 6 and another reactor (Reactor 5) were relocated to the Louisville facility and kept in storage. In 2021, both reactors were modified to meet the Louisville facility's design requirements and were installed in the site's central manufacturing area.

Reactor 6 was equipped with a vent pipe used to vent gases and vapors produced during normal caramel coloring manufacturing operations. One of the vented gases was carbon dioxide, which was generated by the typically controlled exothermic decomposition of the sugar ingredient in the caramel coloring. The vent pipe was equipped with a pressure control valve ("vent valve") that would maintain the pressure at the specified set point by holding back or releasing some of the generated gases and vapors.

Reactor 6 was also equipped with a separate emergency pressure relief pipe. The emergency pressure relief pipe was equipped with a rupture disc and pressure relief valve, which would activate when the reactor pressure reached 75 psig. This emergency pressure relief system served to release pressure from the reactor in the event of high-pressure upsets.

On the day of the incident, the Reactor 6 vent valve failed in the closed position during the manufacture of Product 484, which blocked in the reactor and prevented the release of the gases and vapors that were produced during normal operation. As a result of this blocked-in condition, both the temperature and pressure within the reactor rose abnormally above their set points. These abnormal conditions led to the significant acceleration of the exothermic decomposition reaction of the caramel coloring sugar ingredient. The accelerated reaction released additional heat and produced additional carbon dioxide, causing both the temperature and pressure inside the enclosed reactor to further increase at a rapid rate.

The Louisville facility personnel were not aware that the caramel coloring sugar ingredient could react in this manner to produce such high temperature and pressure. As a result, neither the cooling system nor the emergency pressure relief system had been sized for this accelerated sugar decomposition scenario. On the day of the incident, the sugar decomposition reaction accelerated to the point that it could not be controlled by the cooling water system. The decomposition reaction also produced sufficient pressure inside Reactor 6 to cause the emergency pressure relief system to activate, but the reaction produced more gases and pressure than could be adequately relieved through the installed emergency pressure relief system. As a result, the pressure continued to rise exponentially until Reactor 6 catastrophically ruptured due to the runaway reaction. The maximum pressure recorded before the rupture was 237 psig, which was more than three times Reactor 6's maximum allowable working pressure of 75 psig.

The two employees who died were fatally injured when the blast wave created by the bursting Reactor 6 damaged the control room where they were working, causing the control room to collapse on top of them. The control room was located just 40 feet from Reactor 6 and was not constructed to be blast-resistant.

In addition to the two fatalities and three serious injuries, the explosion caused large pieces of the batch reactor, pipe fragments, instrumentation, valves, and other materials, equipment, and debris to propel outside the facility fence line as far as 400 feet from the facility and resulted in an estimated $30 million in property damage to the facility, as well as $10 million in property damage to nearby homes and businesses. The Reactor 6 shell, which weighed about 2,000 pounds, was launched 245 feet and landed in a residential yard, coming to rest against a home. Local officials issued a shelter-in-place order for a 1-mile radius around the facility. The Louisville facility has since ceased operations and has been demolished.

SAFETY ISSUES

The CSB's investigation identified the safety issues below.

- **Understanding Chemical Reaction Hazards.** Louisville facility management did not understand the hazardous reaction potential of the sugar ingredient in Product 484, which contributed to the inability of the Reactor 6 emergency pressure relief system and cooling system to handle the runaway reaction, as well as the facility management's failure on the day of the incident to recognize the reason for the increasing Reactor 6 pressure and temperature. The facility management's lack of knowledge of the reactive hazards stemmed from their incomplete investigation of caramel coloring ingredients' reaction potential, a lack of industry guidance related to the safe manufacture of caramel coloring, and sugar ingredient safety data sheets that did not warn of the decomposition reaction potential. (Section 4.1)
- **Commitment to Managing Process Safety.** The Louisville facility's implementation of its process safety policies was deficient, resulting in the facility's failure to conduct hazard reviews and clearly document identified hazards and the safeguards in place to protect against them. These deficiencies contributed to (1) to a loss of institutional knowledge about caramel coloring manufacturing hazards after reactivity information regarding one of its products (Product 034) was discovered in 2012, (2) a loss of institutional knowledge about key differences in reactor relief system designs at the facility, and (3) the installation of Reactor 6's undersized relief system. The Louisville facility management did not assign or train any employee to have oversight responsibility and be accountable for the implementation of the process safety policies, which contributed to critical process safety practices not being fully performed. (Section 4.2)
- **Safe Operating Limits.** Safe operating limits are process parameters that, if exceeded, could lead to a significant incident unless immediate corrective action is taken. While Louisville facility procedures required the site to be evacuated if Reactor 6's safe operating limits were exceeded, the CSB found that, due to inadequate training, Louisville facility operators did not fully understand the potential risks of exceeding safe operating limit values. As a result, on the day of the incident, when both the Reactor 6 pressure and temperature safe operating limits were exceeded, personnel continued to troubleshoot the situation and remained inside the building instead of evacuating. When Reactor 6 ruptured, the blast effects caused fatal injuries to two employees in the control room and seriously injured three others. The Louisville facility had failed to adequately train personnel on the Reactor 6 safe operating limits and

had not established alarms or other indicators to alert operators when a safe operating limit was exceeded. (Section 4.3)

- **Facility Siting.** Two employees were fatally injured at the Louisville facility when the blast wave created by the bursting Reactor 6 damaged the control room, causing the control room to collapse on top of them. The control room was located 40 feet from Reactor 6 and was not constructed to be blast-resistant. The Louisville facility did not conduct a facility siting study for the location of the control room, and it was not designed, constructed, or located to protect occupants from hazards created by explosion, fire, or toxic material release. While the Louisville facility was not subject to a specific regulatory requirement to conduct a facility siting analysis, safely locating and protecting facilities, such as control rooms, from process hazards can help protect life and property during an incident. (Section 4.4)
- **Regulatory Coverage of Reactive Hazards.** The Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard and the Environmental Protection Agency (EPA) Risk Management Program (RMP) rule currently use flammability, toxicity, and predefined chemical lists to identify processes subject to regulation, but neither adequately addresses chemicals or processes with reactive hazards that could have catastrophic consequences. Significantly, while caramel coloring sugar ingredients can undergo a highly hazardous chemical reaction, many caramel coloring manufacturing processes are not covered by either the OSHA PSM standard or the EPA RMP rule. Had the Louisville facility been required to implement the process safety management system elements required under the OSHA PSM standard and the EPA RMP rule, including conducting Process Hazard Analysis, Management of Change, and Process Safety Information compilation, the personnel involved in the Reactor 6 design would have had much more robust and reliable opportunities to become aware of the caramel coloring sugar ingredients' decomposition hazards, which should have led to the Reactor 6's emergency pressure relief system being designed to handle an accelerated decomposition scenario, preventing the incident. (Section 4.5)

CAUSE

The CSB determined that the cause of the explosion was a high-pressure condition resulting from the accelerated decomposition of a sugar ingredient. The high pressure could not be adequately relieved through the undersized emergency pressure relief system. The emergency pressure relief system was undersized due to the facility management's fundamental lack of understanding of the chemical reaction hazards associated with sugar ingredients. To prevent the Reactor 6 rupture, the existing emergency pressure relief system (pressure relief valve with rupture disc) would have needed to be four times larger.

Contributing to the incident were serious deficiencies in the facility's implementation of its process safety policies, which contributed to a loss of institutional knowledge about caramel coloring manufacturing hazards after reactivity information regarding one of its products (Product 034) was discovered in 2012. The serious deficiencies in the facility's implementation of its process safety policies led to the installation of an undersized emergency pressure relief system for the reactor.

Contributing to the severity of the incident was the Louisville facility's failure to adequately train and to automatically alert personnel when safe operating limits were reached. As a result, facility personnel continued to troubleshoot while Reactor 6 was in an unsafe condition and did not evacuate the building. Also contributing to the severity of the incident was the lack of a facility siting analysis for the location of the control room, which was situated near the reactor and constructed without blast protection.

RECOMMENDATIONS[a]

Previously Issued Recommendations Reiterated in This Report

To U.S. Environmental Protection Agency (EPA)

2001-01-H-R3 (from the 2002 CSB Reactive Hazard Study)

Revise the Accidental Release Prevention Requirements, 40 CFR 68, to explicitly cover catastrophic reactive hazards that have the potential to seriously impact the public, including those resulting from self-reactive chemicals and combinations of chemicals and process-specific conditions. Take into account the recommendations of this report to OSHA on reactive hazard coverage. Seek congressional authority if necessary to amend the regulation.

To Occupational Safety and Health Administration (OSHA)

2021-02-I-WV-R13 (from the 2002 CSB Reactive Hazard Study, as superseded in the Optima Belle investigation report)

Amend the Process Safety Management Standard (PSM), 29 CFR 1910.119, to achieve more comprehensive control of reactive hazards that could have catastrophic consequences.

- Broaden the application to cover reactive hazards resulting from process-specific conditions and combinations of chemicals. Additionally, broaden coverage of hazards from self-reactive chemicals. In expanding PSM coverage, use objective criteria. Consider criteria such as the North American Industry Classification System (NAICS), a reactive hazard classification system (e.g., based on heat of reaction or hazardous gas evolution), incident history, or catastrophic potential.
- In the compilation of process safety information, require that multiple sources of information be sufficiently consulted to understand and control potential reactive hazards. Useful sources include but are not limited to:
    - Literature surveys (e.g., Bretherick's Handbook of Reactive Chemical Hazards, Sax's Dangerous Properties of Industrial Materials, CAS SciFinder).
    - Information developed from computerized tools (e.g., ASTM's CHETAH, CCPS's Chemical Reactivity Worksheet).
    - Chemical property data in PubChem and the REACH (Registration, Evaluation, and Authorization of Chemicals) dossiers maintained by the European Chemicals Agency (ECHA).

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[a] Givaudan has indicated that the company is considering rebuilding the caramel coloring production facility in a new location. The CSB has not made a recommendation to Givaudan regarding the siting of any such new facility, but the CSB is concerned about the substantial damage that the explosion at the Louisville facility caused to homes in the surrounding neighborhood and the significant risk that was posed to the community by the incident. The CSB urges Givaudan to ensure that any new production facility will not be located in close proximity to a residential area in order to help prevent another community from being put at serious risk.

  - Chemical reactivity test data produced by employers or obtained from other sources following established standards such as:
    - ASTM E537-20, Standard Test Method for Chemicals by Differential Scanning Calorimetry;
    - ASTM E1981-22, Standard Guide for Assessing Thermal Stability of Materials by Methods of Accelerating Rate Calorimetry;
    - ASTM E2550-21, Standard Test Method for Thermal Stability by Thermogravity; and
    - ASTM E1231-19, Standard Practice for Calculation of Hazard Potential Figures of Merit for Thermally Unstable Materials.
  - Relevant incident data from the plant, the corporation, industry, and government.
- Augment the process hazard analysis (PHA) element to explicitly require an evaluation of reactive hazards. In revising this element, evaluate the need to consider relevant factors, such as:
    - Rate and quantity of heat or gas generated.
    - Maximum operating temperature to avoid a runaway reaction from decomposition.
    - Time to Maximum Rate under Adiabatic Conditions (TMR_{ad}).
    - Thermal stability of reactants, reaction mixtures, byproducts, waste streams, and products.
    - Effect of variables such as charging rates, catalyst addition, and possible contaminants.
    - Understanding the consequences of runaway reactions or hazardous gas evolution.

New Recommendations

To Givaudan Facilities that Manufacture Caramel Coloring Products

2024-06-I-KY-R1

Contract a third party to analyze the reactivity of the sugar ingredients in the caramel coloring product manufacturing process by, at a minimum:

a. Conducting calorimetry testing on at least one representative recipe for all caramel coloring product types to determine their temperature and pressure behavior upon heating.

b. Testing the composition of any produced non-condensable gases.

Maintain this information for use during future equipment design efforts and hazard analyses.

2024-06-I-KY-R2

Contract a third party to conduct a hazard analysis of each caramel coloring facility. Require this analysis to address reactivity hazards and include a review of the reactivity data obtained from implementing CSB Recommendation 2024-06-I-KY-R1. Implement the recommendations issued by the third party as a result of the hazard analyses.

2024-06-I-KY-R3

Contract a third party to develop a process safety management system to be used at each caramel coloring facility. This third party shall:

a. Ensure the process safety management system is in alignment with current industry guidance such as the CCPS's *Guidelines for Risk Based Process Safety*.

b. Ensure that the process safety management system requires hazard reviews/analyses to be conducted at prescribed intervals and include:

   (1) the review/incorporation of reactivity data from CSB Recommendation 2024-06-I-KY-R1 and any additional reactivity data obtained during the course of operating any caramel coloring facility,
   (2) the review/analysis of any process changes that could affect relief system designs, and
   (3) the review/updating of the facility siting study from CSB Recommendation 2024-06-I-KY-R7, as appropriate.

2024-06-I-KY-R4

At each caramel coloring facility, hire a new or identify a current employee who is competent in process safety management concepts. Establish this employee's job duties to specifically include overseeing the caramel coloring facility's process safety management system established in 2024-06-I-KY-R3, its implementation, and personnel training on the system's elements.

2024-06-I-KY-R5

For each caramel coloring facility, contract a third party to design adequate emergency pressure relief systems for the vessels involved in caramel coloring manufacturing. Ensure the third party reviews/incorporates all reactivity data obtained from the testing required by CSB Recommendation 2024-06-I-KY-R1 when designing the emergency pressure relief systems. Document and maintain each vessel's relief system design basis for the service life of the vessel.

2024-06-I-KY-R6

For each caramel coloring facility, establish automatic alerts, such as alarms or control screen indications, to notify operators when a safe operating limit has been reached. Follow industry guidance, such as the guidance presented in the Center for Chemical Process Safety Book *Guidelines for Engineering Design for Process Safety (2nd Edition)*, Chapter 5 *General Design*. Provide initial and refresher training for operations personnel on the established safe operating limits including the actions to take if these limits are exceeded.

2024-06-I-KY-R7

Contract a third party to conduct a facility siting study before constructing caramel coloring facility(ies) to help protect facility occupants and critical equipment from hazards created by explosion, fire, or toxic material release, using published industry guidance, such as that in the Center for Chemical Process Safety book, *Guidelines for Siting and Layout of Facilities*.

To Givaudan - Corporate

2024-06-I-KY-R8

Create and fill a corporate senior leadership position responsible for overseeing process safety at all Givaudan caramel coloring facilities or identify a current senior leader who is competent in process safety management concepts to fill this role. Establish this senior leader's job duties to oversee the process safety management system implementation at all Givaudan caramel coloring facilities. Assign this individual to develop corporate-level process safety management system policies to ensure consistent development and implementation of process safety management systems at all Givaudan caramel coloring facilities. One of the policies will address training operations personnel on defined safe operating limits and actions to take if those limits are exceeded.

To International Technical Caramel Association

2024-06-I-KY-R9

Publish a technical safety bulletin for caramel coloring manufacturing that encourages caramel color manufacturers to ensure known hazards, including sugar ingredient decomposition, are addressed. Emphasize the importance of obtaining information on calorimetric properties of sugar ingredients and ensuring appropriately sized emergency pressure relief systems to safely vent pressure and gases that could be produced by sugar ingredient decomposition reactions, as well as other overpressure scenarios identified in hazard analyses. Refer caramel color manufacturers to the CSB's investigation report for additional details. Recommend in the technical safety bulletin that caramel coloring manufacturers implement, as appropriate, process safety management systems that are in alignment with local requirements and chemical industry good practice guidance, such as the Center for Chemical Process Safety *Guidelines for Risk Based Process Safety, Essential Practices for Managing Chemical Reactivity Hazards*, and *Guidelines for Implementing Process Safety Management*.

2024-06-I-KY-R10

Alert association members that manufacture caramel coloring of the November 12, 2024, Givaudan incident and its causes, including but not limited to the sugar ingredient decomposition reaction that led to Reactor 6's rupture.

To International Molasses Corporation LTD.

2024-06-I-KY-R11

Update all invert sugar safety data sheets to include: the decomposition temperature, the consequences of exceeding that temperature, and the decomposition products produced (for example, carbon dioxide).

To Corn Refiners Association

2024-06-I-KY-R12

Alert association members who manufacture corn syrup of the November 12, 2024, Givaudan incident and its causes, including but not limited to the sugar ingredient decomposition reaction that led to Reactor 6's rupture.

Request that they update their corn syrup safety data sheets to include: the decomposition temperature, the consequences of exceeding that temperature, and the decomposition products produced (for example, carbon dioxide).

1 BACKGROUND

1.1 GIVAUDAN

The Givaudan group of companies (“Givaudan”), headquartered in Switzerland, manufactures ingredients for food and beauty products [1], [2]. Givaudan is a global company with facilities located in Africa, Asia, Australia, Europe, North America, and South America [3].

The November 12, 2024, incident occurred at the Givaudan Sense Colour facility in Louisville, Kentucky (“Louisville facility”), which was operated by its subsidiary D.D. Williamson & Co., LLC (“D.D. Williamson”). The Louisville facility produced caramel coloring, a coloring additive used in many types of food and beverages.

1.2 D.D. WILLIAMSON

D.D. Williamson, a fully owned subsidiary of Givaudan, owned and operated the Louisville facility. D.D. Williamson was acquired by Givaudan in December 2021 [4].

D.D. Williamson was founded in 1865 and originally provided malt for beer brewing companies before it pivoted its business operations to begin developing caramel coloring and natural colors[a] for soft drinks and food. D.D. Williamson began producing caramel coloring in Louisville, Kentucky, in 1948, and established its business and technical support services headquarters there in 1965. Before its acquisition by Givaudan in 2021, D.D. Williamson operated 12 facilities globally, including in Africa, Asia, Europe, North America, and South America. Two of its manufacturing facilities[b] were in the United States, including the caramel coloring facility in Louisville, Kentucky, and a natural colors facility in Port Washington, Wisconsin.

1.3 THE LOUISVILLE FACILITY

The Louisville facility (**Figure 1**), which was originally constructed in 1948 and employed about 55 people at the time of the incident, included a central manufacturing area that housed reactors, storage tanks, and other equipment used to produce liquid caramel coloring. The east side of the Louisville facility housed additional storage tanks, administrative offices, and a combined control room and laboratory, constructed in 2012, where employees monitored and controlled the manufacturing operations. The west side of the Louisville facility included a warehouse and a drying area that dried some of the liquid caramel coloring products into powder.

The November 12, 2024, incident occurred when Reactor 6, one of the caramel coloring batch reactors located in the central manufacturing area, overpressured and ruptured. Thirty D.D. Williamson employees and at least four other contractors and visitors were on site at the time of the incident.

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[a] The Natural Food Colours Association (NATCOL) defines natural colors as those that “originate from a wide range of sources like vegetables, fruits, plants, minerals, and other edible natural sources” [42]. D.D. Williamson produces natural colors from red beet, paprika, annatto, and turmeric at the facility in Port Washington, Wisconsin.

[b] D.D. Williamson operated both of these facilities as of November 12, 2024.

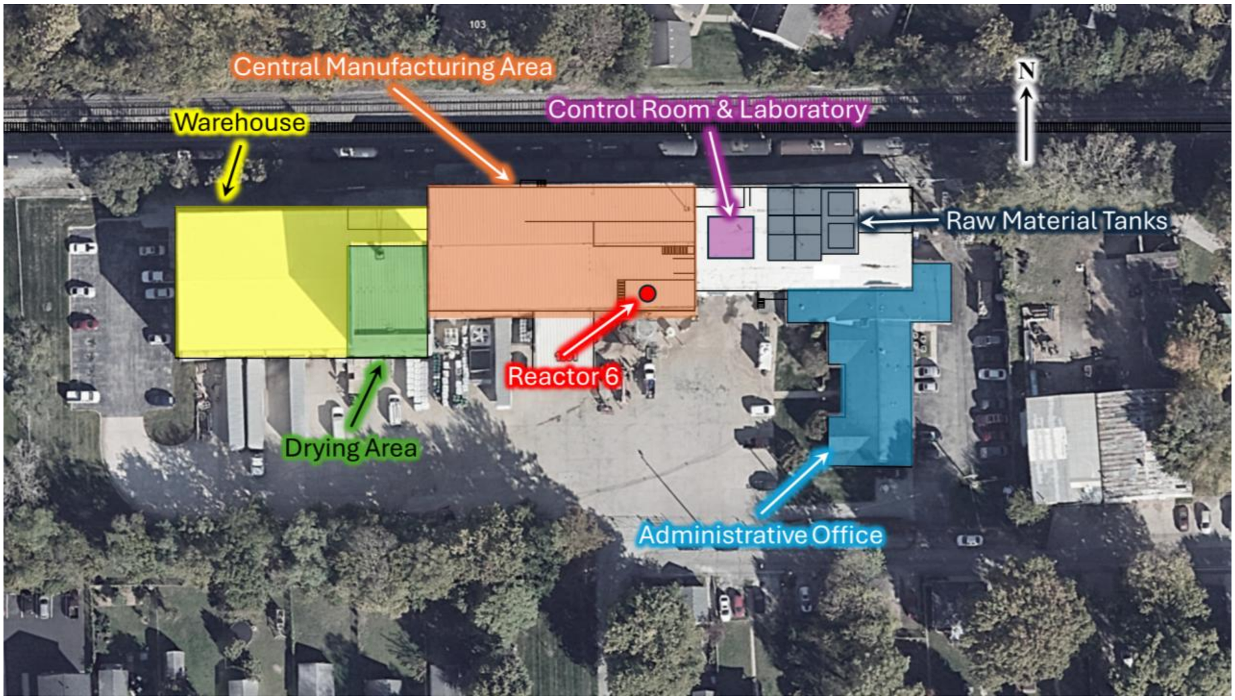

Figure 1. Overhead view of the Louisville facility with key areas identified. (Credit: Google Earth and Givaudan, annotated by CSB)

The Louisville facility was located in a neighborhood composed primarily of residential- and industrial-zoned areas (**Figure 2**).[a] Directly to the north of the Louisville facility was a railroad track, which was used to deliver raw materials, such as corn syrup, to the facility. The nearest residential property was located less than 100 feet from the facility.

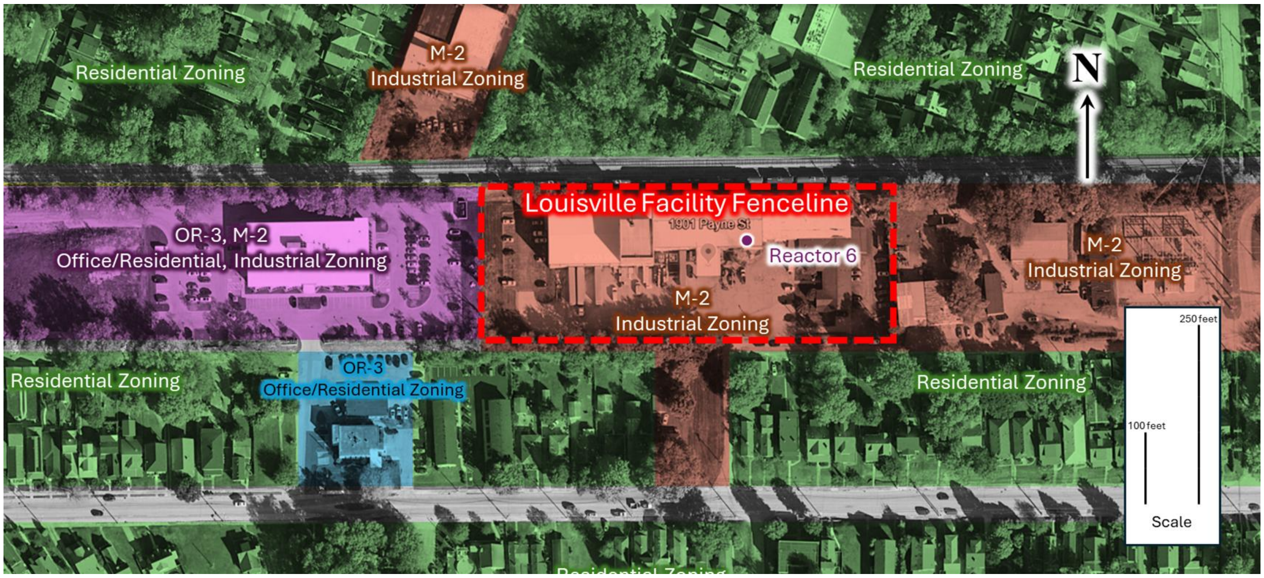

Figure 2. Zoning of properties surrounding the Louisville facility [5]. (Credit: Google Earth, annotated by CSB)

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[a] The land that the Louisville facility was constructed on was zoned as "M-2 Industrial," which permits food processing under the Louisville Metro Land Development Code [43, p. 134].

1.4 CARAMEL COLORING MANUFACTURING PROCESS

The Louisville facility produced liquid caramel coloring in batches by heating sugar[a] with other ingredients until the desired color, among other characteristics, was achieved.[b] Six reactors, Reactor 1 through Reactor 6, were used to manufacture the caramel coloring batches. During each manufacturing operation, operators followed a batch instruction that specified the quantity of raw materials to add to the designated reactor, feed sequences, temperature and pressure set points, and processing durations.

The Louisville facility manufactured many different variations of caramel coloring products, each with different end uses, and each product was assigned an internal product code. On the day of the incident, the Louisville facility was producing caramel coloring Product 484,[c] intended for a food product, inside Reactor 6.

1.5 REACTOR 6

Reactor 6 was installed and began operating at the Louisville facility in 2021. Reactor 6 is shown in **Figure 3**. It was positioned next to Reactor 5, which was also installed in 2021.

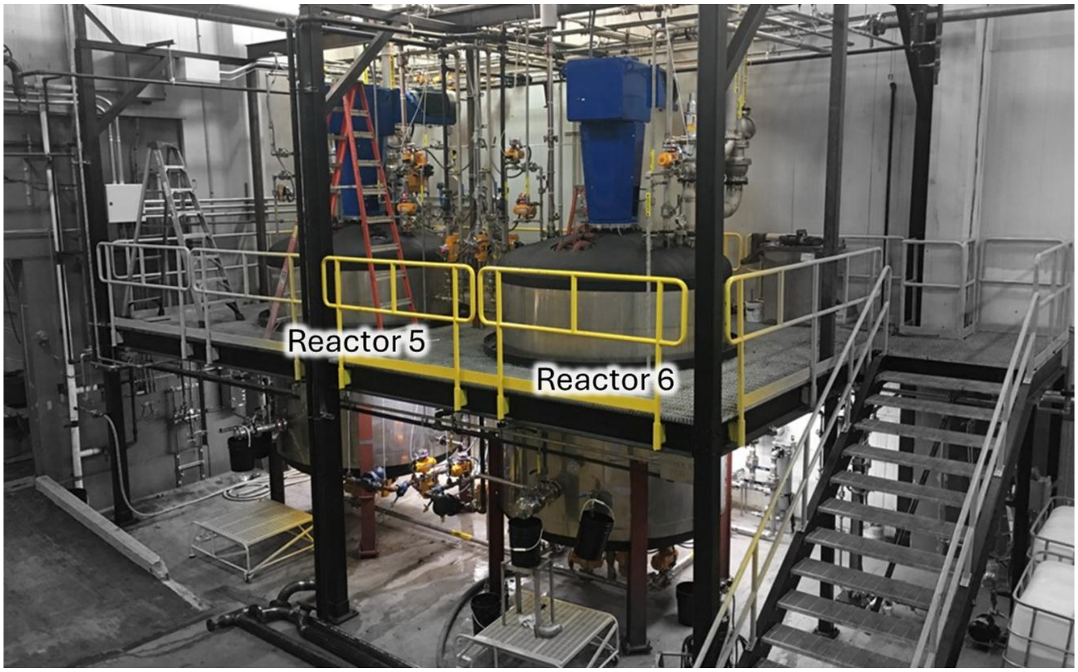

Figure 3. Reactor 5 (left) and Reactor 6 (incident reactor, right) after installation in 2021. (Credit: Givaudan)

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[a] The sugar used during the manufacture of Product 484 was a syrup called invert sugar, a mixture of sucrose, glucose, fructose, and water. Sucrose, a type of sugar, contains a molecule of glucose bonded to a molecule of fructose. Most caramel coloring products manufactured at the Louisville facility used either corn syrup or an invert sugar syrup as the sugar ingredient. Corn syrup is primarily glucose. The invert sugar syrup used in many caramel coloring products was a "medium invert," which is a solution in which approximately 50 percent of the sucrose has been broken down into its component sugars, glucose and fructose.

[b] Caramel color is classified as Class I (plain caramel), Class II (sulfite caramel), Class III (ammonia caramel), or Class IV (sulfite ammonia caramel) based on the ingredients used in the manufacturing process [45]. The Louisville facility manufactured Class I, III, and IV caramel colors.

[c] Product 484 is a Class I caramel. Product 484 is manufactured using water, invert sugar, sodium hydroxide, phosphoric acid, and an antifoam additive.

A simplified depiction of the top portion of Reactor 6[a] is shown in **Figure 4**. Reactor 6 was a 2,500-gallon vessel constructed of 316 stainless steel with a maximum allowable working pressure (MAWP) of 75 pounds per square inch gauge (psig) at a maximum allowable working temperature (MAWT) of 355 degrees Fahrenheit (°F). The reactor contents were mixed by an agitator.

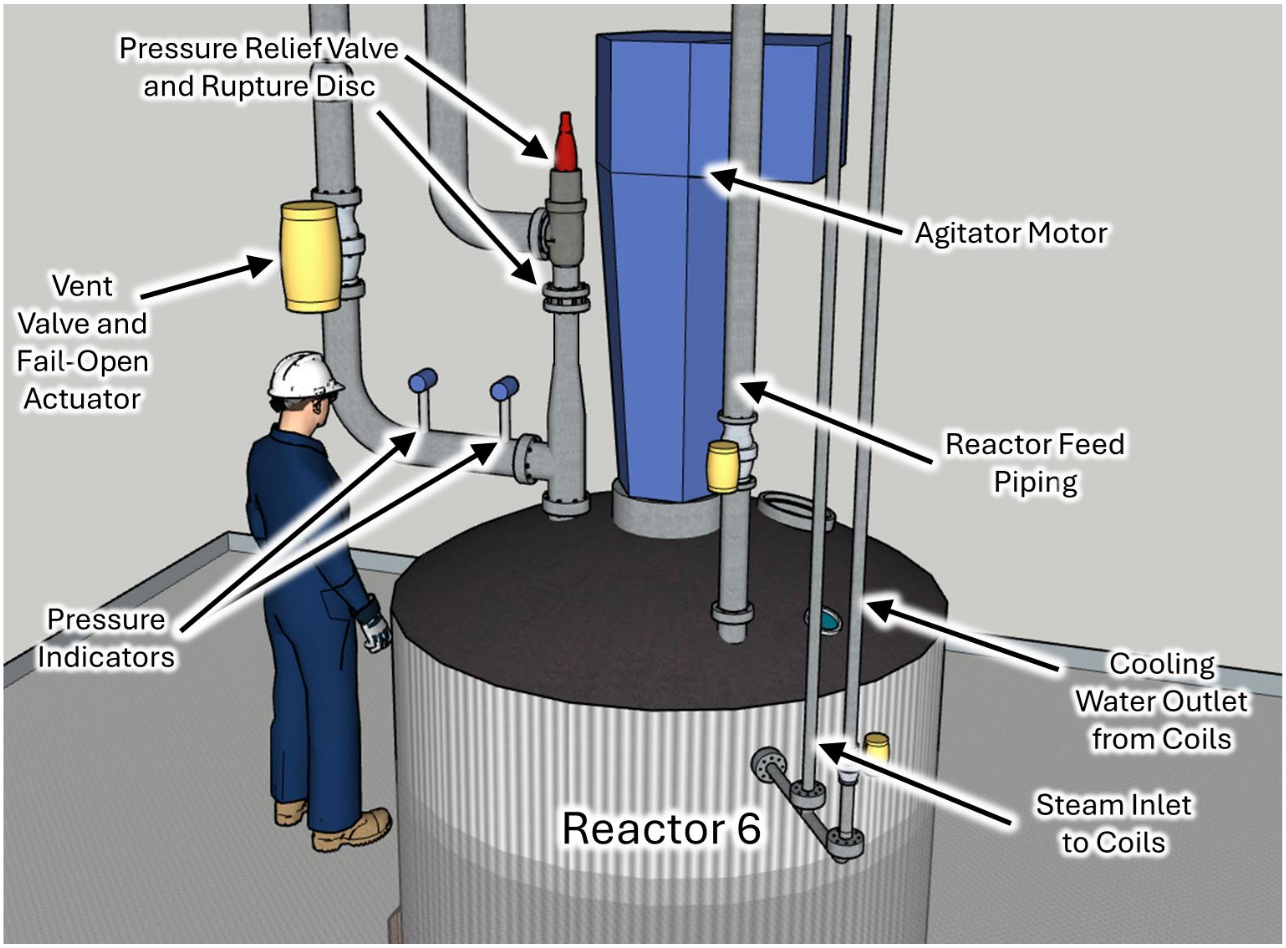

Figure 4. Simplified depiction of the top portion of Reactor 6. (Credit: CSB)

Reactor 6 was equipped with both a vent pipe (used during normal operation) and an emergency pressure relief pipe (used during high-pressure upsets), both of which originated from a single 6-inch nozzle on the head of the reactor (**Figure 5**). The vent pipe, which directed Reactor 6 gases produced during normal operation through a scrubber and to the atmosphere, was equipped with a vent valve (pressure control valve) with a pneumatic actuator that could automatically open and close to control the reactor's pressure. The vent valve position was controlled by a Programmable Logic Controller (PLC), which determined the required vent valve position based on the pressure inside the reactor. When the reactor pressure increased or decreased, the actuator would incrementally open or close the valve to maintain the pressure at the set point. In the event of a loss of actuating

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[a] Reactors 5 and 6 were constructed in 1978. Both reactors originally operated at a D.D. Williamson facility in Modesto, California, which shut down in 2008. After the closure of that facility, the two reactors were relocated to the Louisville facility and kept in storage. In 2021, both reactors were modified to meet the Louisville facility's design requirements and were installed in the site's central manufacturing area.

air pressure, the actuator was designed to move the valve to the open position (fail open), which will be further discussed in *Section 3.2*.

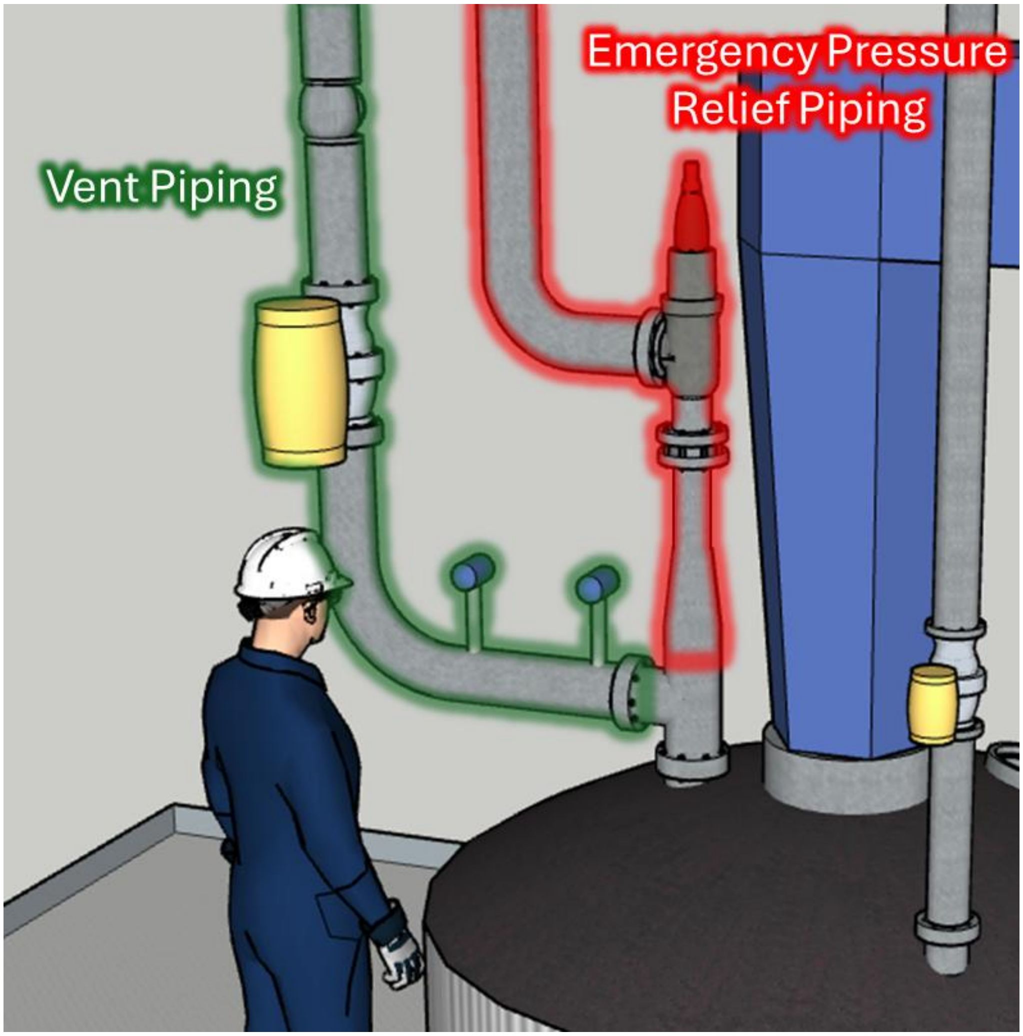

Figure 5. Simplified depiction of vent piping and emergency pressure relief piping. (Credit CSB)

In case of high-pressure events, Reactor 6 was equipped with a rupture disc and pressure relief valve,[a] installed in series, on the emergency pressure relief pipe. The rupture disc had a burst pressure of 75 psig at 355°F, and the pressure relief valve had a 75 psig set pressure. The emergency pressure relief pipe discharged to a 4,500-gallon catch tank before being routed through the scrubber and to the atmosphere.

The reactor temperature was controlled by either steam or cooling water flowing through coils mounted to the inside wall of the reactor (**Figure 6**). The PLC would automatically open valves to apply either steam or cooling water to the coils to maintain the desired reactor temperature.

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[a] The rupture disc was installed between the reactor and the pressure relief valve.

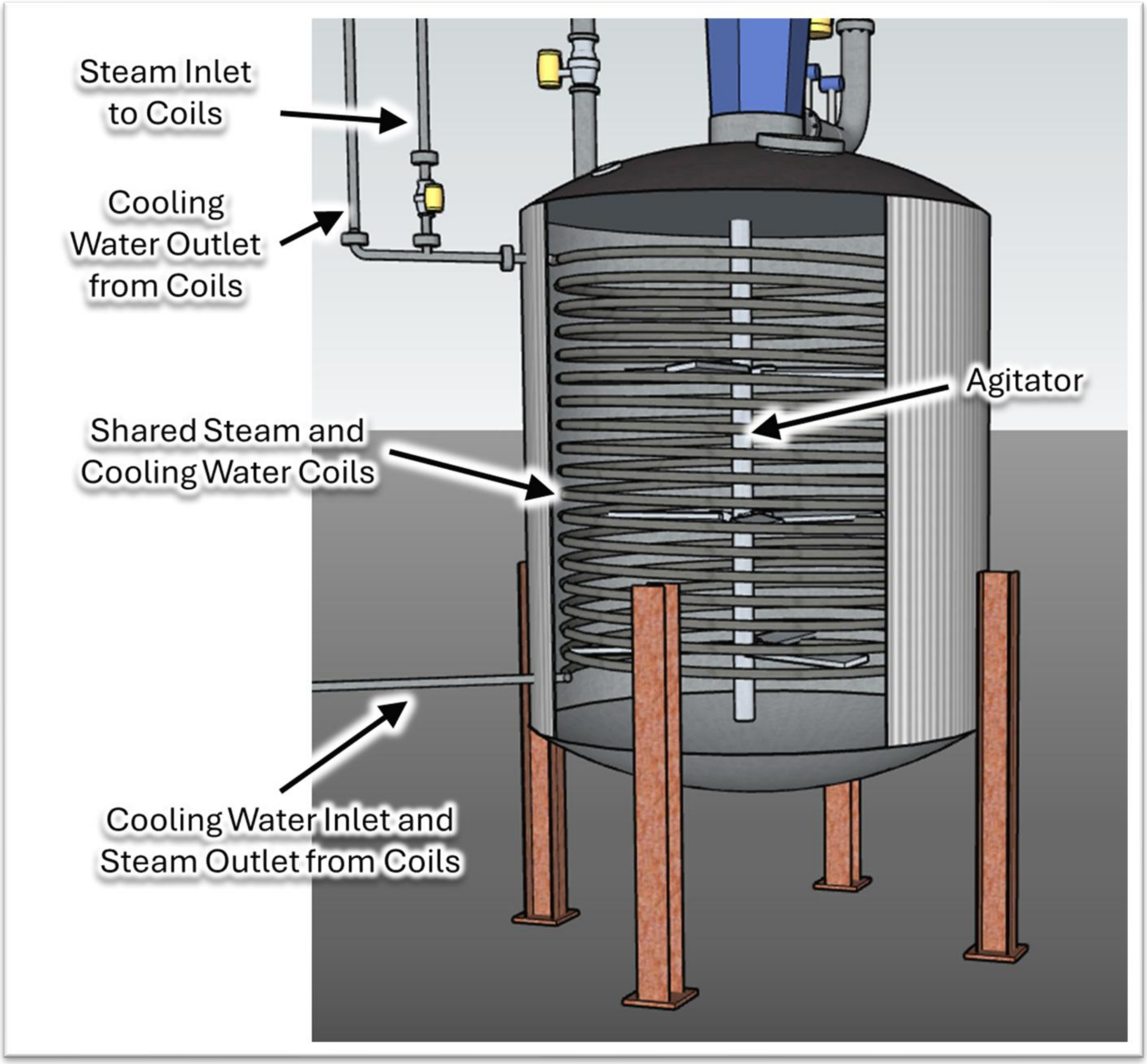

Figure 6. Simplified depiction of the interior of Reactor 6, which included coils for steam and cooling water and an agitator to mix the reactor contents. (Credit: CSB)

Raw materials were fed into Reactor 6 via piping connected to the top head of the reactor. The materials were fed into the reactor in quantities specified by operators using the control room computer.[a] Reactor 6 was also equipped with a sight glass on the top head of the reactor, which was used to verify that the reactor was clean and empty before starting a new batch and to monitor for foaming throughout each batch.

Throughout the batch sequence and upon batch completion, operators would obtain samples of the reactor contents and deliver them to the combined laboratory/control room, where the laboratory technician would

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[a] For smaller, specialty additives, operators could manually add the materials through the vessel manway.

measure properties including pH, color, and specific gravity. The laboratory technician would then instruct the operators to adjust the batch operation, if needed, to achieve the desired product properties.

After the completion of a batch, operators would transfer the product to a storage tank. Once the product was transferred, the reactor would be washed using either a caustic wash or a water wash and verified to be clean before starting a new batch.

1.6 REGULATORY COVERAGE

The Louisville facility was not subject to either the Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard[a] or the Environmental Protection Agency (EPA) Risk Management Program (RMP) rule.[b] Both regulations only apply to facilities that store or use certain specified chemicals above defined threshold quantities. Portions of the facility were once covered by the EPA RMP rule because of the amount of aqueous ammonia stored on site, but in 2007 the facility reduced its aqueous ammonia storage below EPA's defined threshold quantity and as a result was no longer covered by the regulation.

The facility was, however, covered by U.S. Food and Drug Administration (FDA) regulations governing the safety of its food products for consumers[c,d] and was also subject to pressure vessel safety requirements issued by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code,[e] which the Commonwealth of Kentucky has adopted as law.[f] The Louisville facility was also subject to OSHA's General Duty Clause,[g] as well as EPA's Clean Air Act General Duty Clause,[h] which require that facilities be designed and maintained to protect workers and the environment.

1.7 DESCRIPTION OF SURROUNDING AREA

Figure 7 shows the location of the Louisville facility and depicts the area within 1, 2, and 3 miles of the facility. It also summarizes demographic data for Census tracts in the approximate 1-mile vicinity of the Louisville

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[a] 29 C.F.R. § 1910.119 *Process safety management of highly hazardous chemicals*

[b] 40 C.F.R. § 68 *Chemical Accident Prevention Provisions*

[c] 21 CFR § 73.85

[d] The CSB has investigated other process safety incidents at food manufacturing facilities, including Cuisine Solutions (2024), Foundation Food Group (2021), Didion Milling Company (2017), MGPI (2016), ConAgra Foods (2009), and Imperial Sugar (2008).

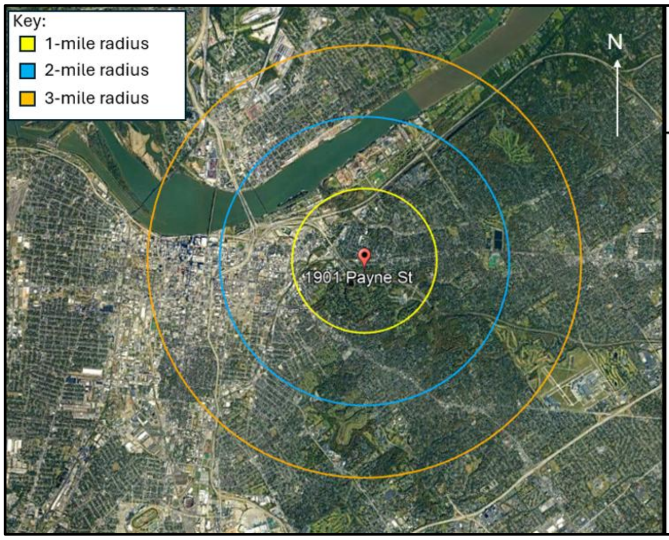
[e] The 2021 edition of the ASME Boiler and Pressure Vessel Code, Section XIII states, "The rules of this section provide the requirements for the overpressure protection of pressurized equipment such as boilers, pressure vessels, and piping systems. Overpressure protection methods include (1) releasing excess pressure by use of pressure relief devices, (2) applying controls to prevent an increase in pressure (overpressure protection by system design), (3) using a combination of (1) and (2)[.] […] [D]uties [required for code compliance] include […] determination of all potential overpressure scenarios and of the method of overpressure protection used to mitigate each scenario[.]"

[f] Kentucky Administrative Regulations (KAR) Title 815, Chapter 015, Regulation 025 *New installations, general design, construction, and inspection criteria for boilers, pressure vessels, and pressure piping*.

[g] The OSHA General Duty Clause states: "Each employer […] shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees [.]" 29 U.S. Code § 654 (a)(1)

[h] The EPA General Duty Clause states: "The owners and operators of stationary sources producing, processing, handling or storing such substances [i.e., a chemical in 40 CFR part 68 or any other extremely hazardous substance] have a general duty [in the same manner and to the same extent as the general duty clause in the Occupational Safety and Health Act] to identify hazards which may result from (such) releases using appropriate hazard assessment techniques, to design and maintain a safe facility taking such steps as are necessary to prevent releases, and to minimize the consequences of accidental releases which do occur." 42 U.S. Code § 7412 (r)(1)

facility. There are over 17,500 people residing in over 11,000 housing units, most of which are multi-unit properties, within approximately 1 mile of the Louisville facility [6]. Detailed demographic information is included in Appendix E.



Pop.	Characteristics		Per Capita Income	Percent Poverty	Number of Housing Units	Types of Housing Units	
17,573	White	75%	$50,313	12%	11,114	Single Unit	36%
	Black	13%				Multi Unit	64%
	Asian	4%				Mobile Home	0%
	Hispanic	5%					
	Two+	3%					

Figure 7. Location of Louisville facility and summary of demographic data for population within approximately 1 mile of facility (Credit: Left image: Google Earth, annotated by CSB; Right table: data from Census Reporter [6])

1.8 PREVIOUS INCIDENT IN APRIL 2003

In 2003, the Louisville facility experienced another fatal chemical accident in which a caramel coloring pressure vessel overpressured and catastrophically ruptured, fatally injuring one worker and causing significant damage to the facility. Both the U.S. Chemical Safety and Hazard Investigation Board (CSB) and EPA investigated the incident. The CSB issued recommendations to the facility to improve the process safety practices there, and EPA entered into a Consent Decree[a] with D.D. Williamson for violating the RMP rule that detailed specific actions the company was required to take. As described in this section, these actions led the Louisville facility to identify reactive hazards associated with one of its caramel coloring product recipes (Product 034) and to implement process design changes to prevent equipment ruptures from the identified reaction.

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[a] A Consent Decree is "a legal document, approved by a judge, that formalizes an agreement reached between the EPA and one or more potentially responsible parties (PRPs) outlining the terms under which that PRP(s) will conduct all or part of a response action, pay past costs, […] or comply with regulations where failure to comply caused EPA to initiate regulatory enforcement actions" [46, p. 4].

1.8.1 2003 INCIDENT DESCRIPTION

On April 11, 2003, a vessel containing caramel coloring overpressured and exploded at the Louisville facility, which at the time was owned and operated by D.D. Williamson [7, p. 9]. The CSB investigated the 2003 incident and published a report detailing the agency's findings and recommendations [7].

Leading to the incident, operators had been heating caramel coloring inside the vessel[a] (**Figure 8**) to a target temperature of 160ºF. The vessel was not equipped with a process control or alarm system, and operators monitored the vessel conditions using local temperature and pressure gauges. While heating the vessel, the operators were also conducting other work, and they did not notice when the vessel temperature rose above 160ºF. The vessel, which had a MAWP of 40 pounds per square inch (psi), was not equipped with a pressure relief device.[b] The air vent valve (**Figure 8**) was also likely closed while the vessel was being heated, blocking all relief capability. The pressure in the vessel increased as the caramel coloring overheated until the vessel overpressured and failed catastrophically (**Figure 9**).

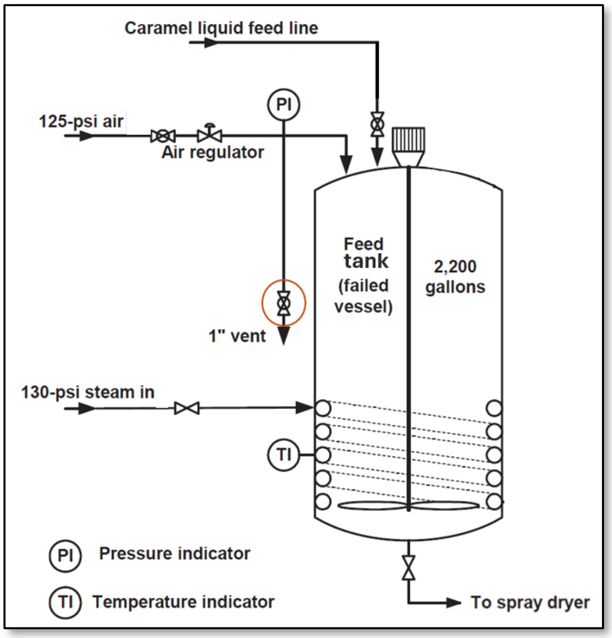

Figure 8. Schematic of vessel involved in 2003 incident. The vessel was not equipped with a pressure relief device. It was equipped with a vent line (1" vent) that was most likely closed as the caramel liquid heated before the incident. (Credit: CSB)

Figure 9. Left photo: Top head of ruptured vessel from 2003 incident; Right photo: shell of ruptured vessel from 2003 incident. (Credit: CSB [7])

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[a] The vessel functioned as a feed tank for a spray dryer that produced powdered colorants [7, p. 9].

[b] The 2001 edition of the ASME Boiler and Pressure Vessel Code stated that "[a]ll vessels (having an internal operating pressure exceeding 15 psi) shall be provided with relief devices… It is the responsibility of the user to ensure that the required pressure relief devices are properly installed prior to initial operation." The Commonwealth of Kentucky adopted ASME Boiler and Pressure Vessel Code requirements as law for both boilers and pressure vessels beginning in 1980.

The incident fatally injured one worker, caused significant site damage, released 26,000 pounds of aqueous ammonia, and forced 1,500 people to shelter in place [7, p. 9].

1.8.2 2003 INCIDENT RESPONSIVE ACTIONS

The CSB's investigation of the 2003 incident found that D.D. Williamson did not conduct engineering reviews to understand the potential hazards of its process or select safeguards to protect from those hazards, despite being required to perform these activities under the EPA RMP rule, which it was covered by at the time of the 2003 incident.[a] The CSB recommended at that time that D.D. Williamson "implement a hazard evaluation procedure to determine the potential for catastrophic incidents and necessary safeguards" [7, p. 47].

In response to this recommendation, in 2008 D.D. Williamson hired a third-party consulting firm to assist the company in completing a Hazard and Operability Study (HAZOP).[b] One of the recommendations issued in the HAZOP was to "investigate the heat of reaction between ammonium bisulfite and ammonia" to determine how this may affect existing equipment design.[c]

In 2009, EPA entered into a Consent Decree with D.D. Williamson requiring the Louisville facility to make safety improvements after its "failure to fulfill its [obligations under the EPA general duty clause] and failure to meet its obligations pursuant to the risk management plan requirements" before and after the 2003 incident. The Consent Decree required the facility to, among other actions, implement the third-party consulting firm's HAZOP recommendations.

In 2012, during the Consent Decree implementation period, D.D. Williamson took action on the 2008 HAZOP recommendation to investigate the heat of reaction between ammonium bisulfite and ammonia. D.D. Williamson conducted the recommended testing on the recipe used to manufacture its Product 034,[d] which included ammonium bisulfite and ammonia as ingredients, along with corn syrup, phosphoric acid, and water. Calorimetry testing was conducted on these Product 034 ingredients to understand how these ingredients behaved when heated.

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[a] 40 C.F.R. § 68.50 *Chemical Accident Prevention Provisions – Hazard Review* "The owner or operator shall conduct a review of the hazards associated with the regulated substances, process, and procedures. […] The owner or operator shall document the results of the review and ensure that problems identified are resolved in a timely manner. […] The review shall be updated at least once every five years. The owner or operator shall also conduct reviews whenever a major change in the process occurs; all issues identified in the review shall be resolved before startup of the changed process."

[b] A HAZOP uses an interdisciplinary team to systematically go through entire processes and operations using guidewords to initiate discussions about deviations and the applicable safeguards to protect against undesired consequences resulting from the deviations [38, p. 115].

[c] In the 2008 HAZOP, high pressure deviation was evaluated for the reactors. The identified possible causes of high pressure included relief valve failure; a blocked vent valve, vent pipe, or vent nozzle; rupture disc failure; check valve in vent piping failure; vent valve failure; mischarge of material to reactor; and steam coil failure. A sugar decomposition reaction had not been identified as a cause of high pressure. The HAZOP listed the following safeguards as protection against high pressure: "automatic cooling, ability to dump materials in cooker to sewer, pressure relief and vent valve to acid scrubber, inspection of vent line to ensure line is not plugged, plant emergency procedures, and preventative maintenance procedures – including coils and other equipment."

[d] D.D. Williamson had also determined that Product 034 was its most hazardous product because it generated the most heat during the manufacturing process.

Figure 10 shows the 2012 testing results. When heated in an enclosed container, the Product 034 ingredients experienced a large temperature increase due to an exothermic chemical reaction (exotherm), as well as a significant pressure rise due to the formation of non-condensable gases. D.D. Williamson did not conduct further tests to determine which chemical components reacted (decomposed) to cause this pressure and temperature behavior. As will be described in *Section 3.1***,** after the 2024 incident, the CSB conducted similar testing on both the Product 484 ingredients (2024 incident ingredients) and the sugar ingredient alone, and both tests exhibited similar behavior to that observed in the 2012 tests.

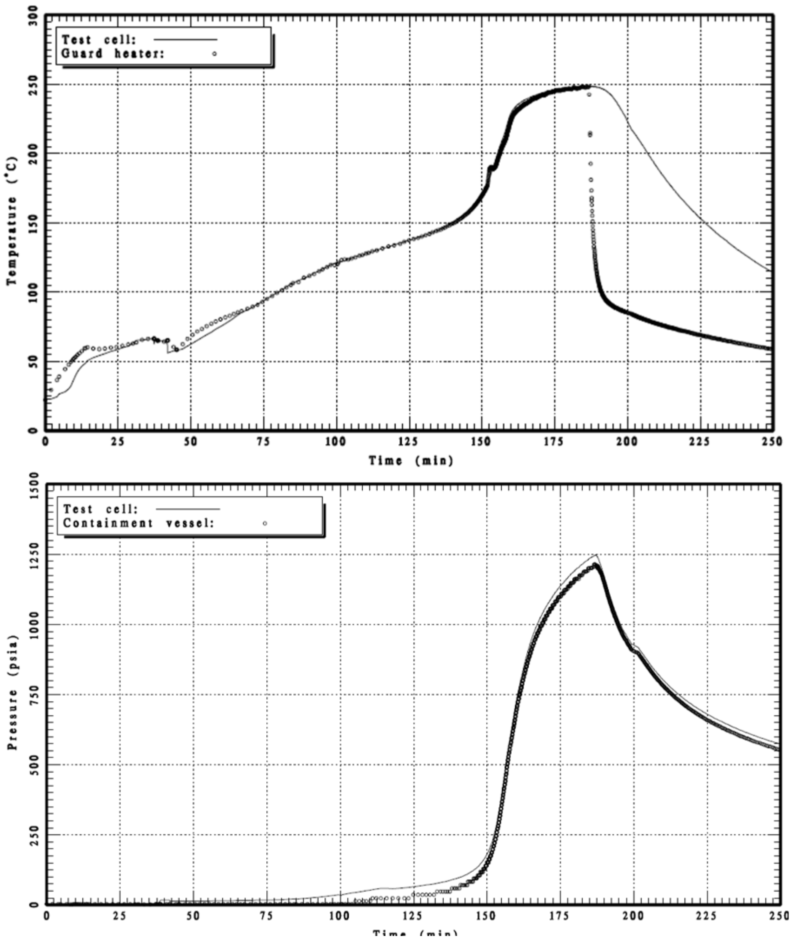

Figure 10. Results from D.D. Williamson's 2012 reactivity testing of Product 034 ingredients (corn syrup, phosphoric acid, water, ammonium bisulfite, and ammonia). (Credit: Givaudan)

1.8.3 EQUIPMENT CHANGES AFTER THE 2012 REACTIVITY TESTS

D.D. Williamson provided the 2012 test results to an outside consultant, who determined that the reactors used to produce Product 034 needed larger relief systems to relieve the pressure and gases that could form from the observed reaction.[a] At that time, the facility had four caramel coloring reactors (Reactors 1–4), and only two of the reactors (Reactor 3 and Reactor 4) were used to produce Product 034, among other products. In response to the consultant's recommendations, in 2013, D.D. Williamson enlarged the relief systems for Reactors 3 and 4. The Reactor 3 and Reactor 4 relief valves, which had a 4.186-square-inch orifice area, were replaced with relief valves with a 10.304-square-inch orifice area. The relief system discharge piping for Reactors 3 and 4 was also modified to improve relief capacity.

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[a] The consultant recommended that D.D. Williamson increase the size of the pressure relief valves on the reactors that were used to produce Product 034 to have an orifice area greater than 7.4 square inches.

D.D. Williamson did not enlarge the relief systems for Reactors 1 or 2, however, as they were not used to produce Product 034 at the time. D.D. Williamson also did not conduct additional reactivity testing of any other product recipes, which will be further discussed in *Section 4.1*.

In 2021, D.D. Williamson installed two additional reactors, Reactor 5 and Reactor 6,[a] to increase the site's manufacturing capacity. As noted in Section 1.5 above, Reactors 5 and 6 were constructed in 1978 and were originally operated at a D.D. Williamson facility in Modesto, California, which shut down in 2008. After the closure of the Modesto facility, the two reactors were relocated to the Louisville facility and kept in storage. In 2021, both reactors were modified to meet the Louisville facility's design requirements and were installed in the site's central manufacturing area. The Louisville facility designed the pressure relief system for the two additional reactors based on the Reactor 2 pressure relief system (4.186-square-inch orifice area), because the two additional reactors were similar in size to Reactor 2 and were to be used to manufacture the same types of products. The facility did not possess any documentation detailing the design basis for the Reactor 2 emergency pressure relief system. While Reactors 5 and 6 were to be used to manufacture a range of caramel coloring products, the Louisville facility did not consider the 2012 caramel coloring reactivity testing results when designing the relief systems for Reactors 5 and 6. As a result, the Reactor 5 and Reactor 6 relief systems were *not* designed to relieve the pressure that could be produced by the reaction identified in the 2012 testing or by the hazardous reaction of any other product recipes.

Later in 2021, Givaudan acquired D.D. Williamson and began operating Reactors 5 and 6 at the Louisville facility. In November 2024, Reactor 6 overpressured and ruptured when Product 484 ingredients experienced a runaway (uncontrolled) reaction resulting in a rapid temperature and pressure rise, as described in the section below.

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[a] Kentucky law requires that all new pressure vessels be installed per National Board Inspection Code guidance and inspected by the Kentucky Department of Housing, Buildings and Construction, Plumbing Division, Boiler Section, the authority having jurisdiction (AHJ), before operation. Neither the site personnel nor the contractor installing Reactors 5 and 6 submitted an installation permit to the AHJ, and the AHJ never inspected the installation. After the incident, the contractor hired to install Reactors 5 and 6, Cochran Mechanical, was fined $500 by the Kentucky Department of Housing, Buildings and Construction for failure to apply for an installation permit.

2 NOVEMBER 12, 2024, INCIDENT DESCRIPTION

2.1 START OF PRODUCT 484 BATCH IN REACTOR 6

On November 12, 2024, Givaudan operators were preparing Product 484[a] inside Reactor 6. To produce Product 484, operators followed a batch instruction that detailed (1) the types and quantities of materials to add to Reactor 6, (2) the raw material feed sequences, and (3) important process conditions such as temperature and pressure set points. Product 484 included the following raw material ingredients: sugar,[b] water, sodium hydroxide, and phosphoric acid.[c] An antifoam additive was also used to reduce foaming during the batch operation.

On November 12, 2024, at 10:22 a.m., operators began the caramel coloring batch sequence. Operators followed the batch instruction, and normal operations were observed during the first half of the batch production process.[d,e]

At 2:17 p.m., in accordance with the batch instruction, operators set the Reactor 6 pressure set point to 12 psig and the temperature set point to 300°F. The programmable logic controller (PLC) automatically closed the vent valve at the top of Reactor 6 to allow the pressure inside the vessel to increase to the set point. The PLC also opened the steam valve to allow steam to flow through the coils to increase the reactor temperature to the set point. After these adjustments, both the temperature and pressure inside Reactor 6 began to rise. When the pressure reached the 12 psig set point, the vent valve position was automatically adjusted as commanded by the PLC for 16 minutes to maintain the pressure at 12 psig.

Evidence collected by the CSB indicates that at 2:39 p.m., the vent valve moved to the closed position[f] despite not being commanded to do so by the PLC (see *Section 2.2*). When the vent valve closed, the reactor pressure exceeded the 12 psig set point (**Figure 11**). The PLC commanded the vent valve to fully open at 2:40 p.m., but the valve did not open (see *Section 2.2*). The pressure continued to rise. Because the temperature had not yet reached its set point of 300°F, steam was being applied to the coils at this time, which caused the temperature also to continue to rise. At 2:47 p.m., the reactor temperature exceeded the 300°F set point, and the PLC shut the steam valve and opened the valve supplying cooling water to the coils.[g] After these changes, however, both the temperature and pressure continued to rise.

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[a] The Louisville facility has been manufacturing Product 484 since at least 2012. The Louisville facility never conducted calorimetry testing of Product 484 ingredients prior to the November 12, 2024, incident.

[b] The sugar used was a syrup called invert sugar, a mixture of sucrose, glucose, fructose, and water.

[c] Product 484 had been produced at least four times in Reactor 6 in the month leading to the incident without experiencing adverse events.

[d] During periodic checks of the batch production, employees monitored for foaming in Reactor 6 through the sight glass and did not observe any abnormal behavior. The final check of Reactor 6 was completed at 2:45 p.m.

[e] The CSB compared the Product 484 operational data from the day of the incident with data from previous Product 484 batches prepared in Reactor 5 and Reactor 6. The batch sequence, temperature, and pressures in the incident batch were similar to previous batches until approximately 2:39 p.m. when the vent valve closed.

[f] The Louisville facility did not collect data indicating the actual position of the vent valve. The CSB determined the vent valve position at this time by analyzing other data, including surveillance footage and scrubber data.

[g] The PLC was programmed to activate the Reactor 6 cooling water when the temperature exceeded 305°F.

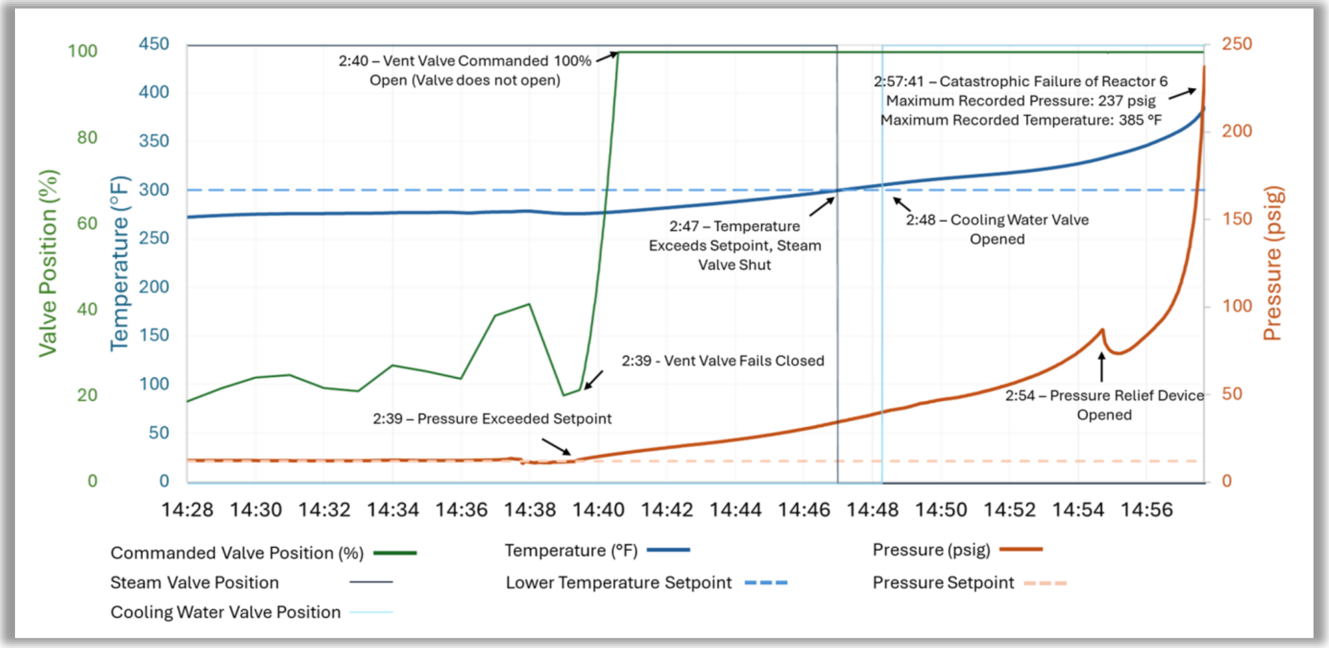

Figure 11. Process data from Reactor 6 leading up to the explosion. (Credit: CSB)

2.2 CLOSED VENT VALVE

Operators observed the abnormal pressure and temperature increases from the control room.[a] At 2:53 p.m., a maintenance technician, who had been made aware of the abnormal Reactor 6 conditions, approached Reactor 6 to identify any mechanical malfunctions of the reactor's equipment. Surveillance footage shows, and interviews with Louisville facility personnel confirm, that the maintenance technician used a wrench on the Reactor 6 vent valve actuator and attempted to manually adjust the valve's position (**Figure 12**). Based on the position of the wrench and other PLC data,[b] the CSB determined that the vent valve was in the closed position (**Figure 13**), despite the PLC commanding it to be fully open and despite the valve being equipped with a fail-open actuator. The surveillance footage indicates that the maintenance technician was unable to move the vent valve to the open position, and it remained closed. The maintenance technician then exited the Reactor 6 mezzanine at 2:54 p.m. After the incident, the vent valve was recovered and found to be in the closed position.

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[a] The image of Reactor 6 on the control screen turned red at 2:52 p.m., indicating abnormal operating conditions. The operators, however, were already aware of the unusually high pressure and temperature, as they were monitoring this data from the control room.

[b] PLC data indicates that while the vent valve modulated to maintain the 12 psig pressure set point, the scrubber temperature increased and the scrubber pressure fluctuated, both of which are consistent with hot exhaust from Reactor 6 flowing to the scrubber. After the vent valve stopped modulating, the scrubber temperature decreased and the scrubber pressure stabilized, which is consistent with vapor flow from Reactor 6 to the scrubber stopping. Both the scrubber temperature and pressure again began to increase after the Reactor 6 pressure relief system activated.

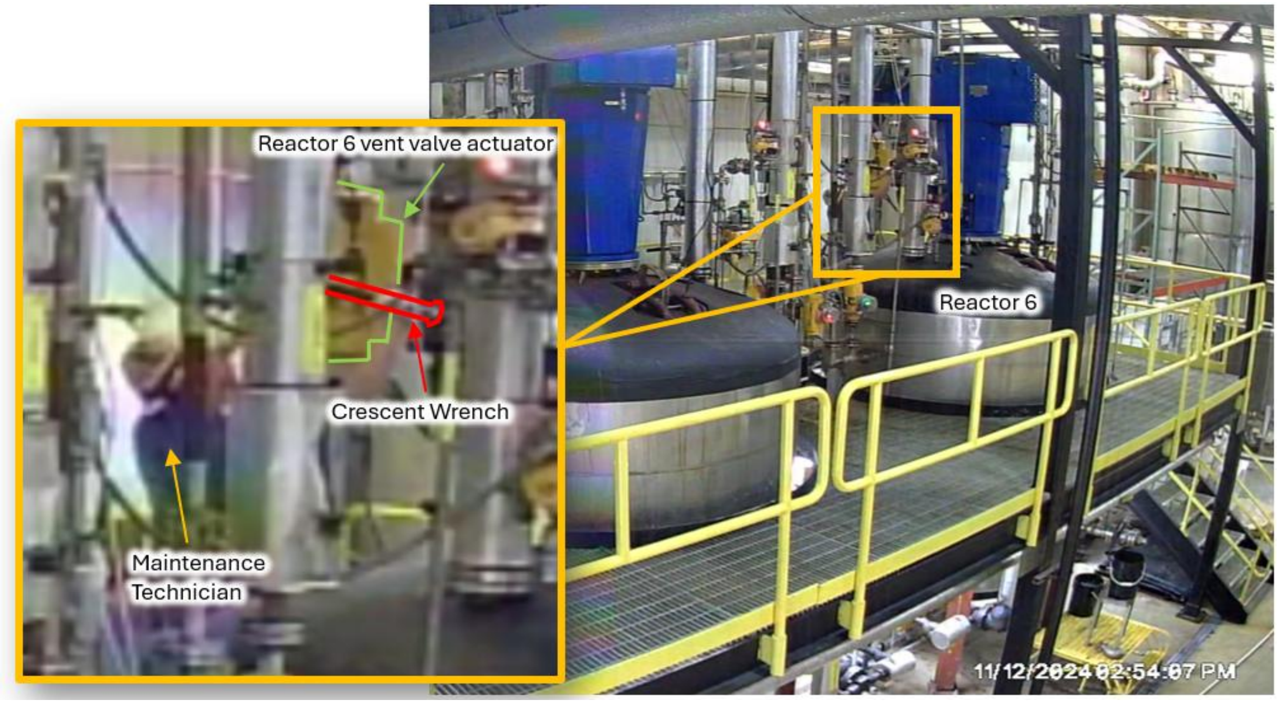

Figure 12. Surveillance footage showing a maintenance technician using a crescent wrench on the actuator to attempt to open the Reactor 6 vent valve. The crescent wrench is positioned perpendicular to the actuator, indicating the valve was in the closed position. (Credit: Givaudan, annotated by CSB)

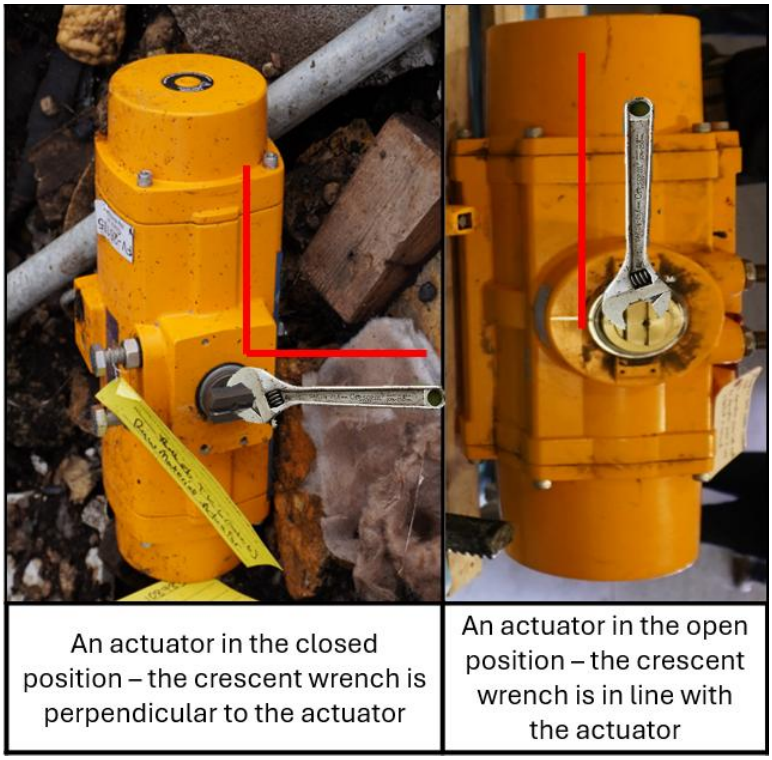

Figure 13. Left photo: example actuator in closed position; Right photo: example actuator in open position. (Wrench placed for illustration) (Credit: CSB)

2.3 REACTOR 6 EXPLOSION

The Reactor 6 pressure and temperature continued to rise, and at 2:54 p.m., the high reactor pressure caused the Reactor 6 emergency pressure relief system to open, which temporarily reduced the Reactor 6 pressure before it again began to rise at a rapid rate (**Figure 11**).[a] Operators and other personnel in the control room were monitoring the process data and were attempting to determine why Reactor 6 was experiencing such high temperatures and pressures, as they had not seen this type of temperature and pressure behavior before (**Figure 14**).

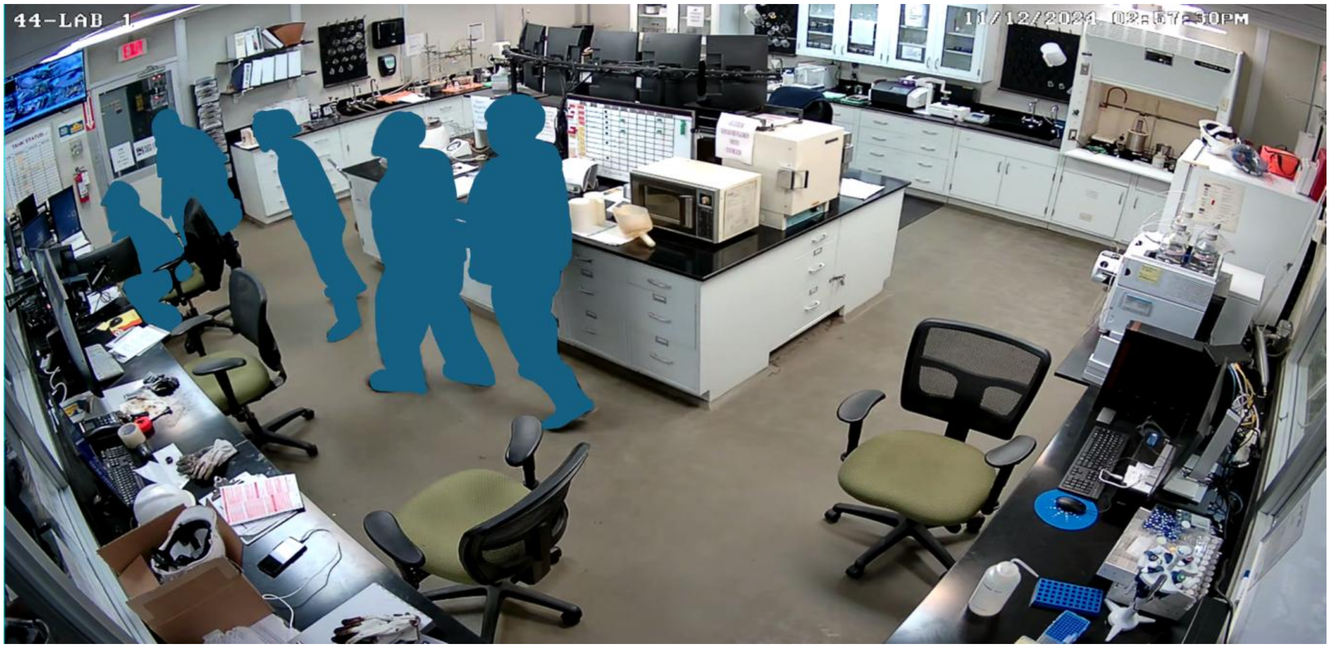

Figure 14. Location of personnel inside the control room at the time of the incident. Six employees were in the control room. (One employee, not visible in this photo, was located behind the raised computer monitors.) (Credit: Givaudan, redacted by CSB)

At 2:57 p.m., Reactor 6 ruptured due to high internal pressure, creating a catastrophic explosion. The maximum temperature recorded by the PLC before the rupture was 385°F,[b] 30 degrees above the MAWT of 355°F. The maximum pressure recorded before the rupture was 237 psig,[c] more than three times the MAWP of 75 psig.

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[a] All six of the reactors had independent relief and vent piping, but they all discharged to the same relief equipment. Reactors 1–5 were operating within their safe operating limits and were not relieving to the relief system on the day of the incident. The full capacity of the relief system was available to Reactor 6 on the day of the incident.

[b] The upper temperature range for the thermocouple in service was approximately 500°F.

[c] The upper equipment limit for the pressure transmitter in service was approximately 300 psig.

2.4 INCIDENT CONSEQUENCES

At the time of the Reactor 6 explosion, six employees were inside the control room.[a] Other employees were working in the central manufacturing area and throughout the facility. Two employees who were inside the control room—the maintenance technician and a rail operator—were fatally injured when the Reactor 6 explosion caused the control room to collapse on them. Three other employees at the facility were seriously injured. Two of these employees, a reactor operator and maintenance technician present in the control room, were admitted to the hospital for broken ribs and cuts and bruises, respectively. The third employee, an administrative assistant located in a nearby office area, was admitted to the hospital for a concussion.

The facility was destroyed by the explosion (**Figure 15**), resulting in $30 million in property damage to the facility. An additional $10 million in offsite property damage occurred when debris, caramel coloring, and explosion forces impacted properties in the nearby neighborhood, shattering windows, damaging structures, and causing a power outage. Fragments of the exploded Reactor 6 flew as far as approximately 400 feet from the facility. Large pieces of Reactor 6 (**Figure 16**), pipe fragments, instrumentation, valves, and other debris were recovered from the yards of the residences surrounding the facility. The Reactor 6 shell, which weighed about 2,000 pounds, was launched 245 feet and landed in a residential yard, coming to rest against a home.

Local officials issued a shelter-in-place order for the 1-mile radius around the facility for about an hour and 30 minutes. The shelter-in-place order affected two nearby elementary schools and one K-12 school, and dismissal at the schools was delayed [8].

Figure 15. The Reactor 6 explosion destroyed the Louisville facility. (Credit: CSB)

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[a] The six employees included two reactor operators, two maintenance technicians, a rail operator, and a laboratory technician. The two reactor operators and two maintenance technicians were troubleshooting the Reactor 6 operation leading to the incident. The rail operator was present in the control room because his work-station was located there, and the laboratory technician was present because the control room was equipped with laboratory equipment used to test caramel coloring product quality.

Figure 16. Locations of Reactor 6 debris scattered throughout the surrounding neighborhood. The vessel shell weighed about 2,000 pounds. (Credit: Map: Google Earth, annotated by CSB; Photo 1: Dylan Lovan, Associated Press via Louisville Public Media [9]; Photo 2: WDRB News [10]; Photo 3: Louisville Courier Journal [11])

2.5 EVACUATION AND EMERGENCY RESPONSE

Figure 17. Damage to a nearby power line, which prevented employees from meeting at the planned muster location. (Credit: Matt Stone, Louisville Courier Journal [11])

Debris and a downed power line (**Figure 17**) caused by the explosion prevented employees from evacuating to their planned emergency gathering location. Instead, employees who evacuated from the east side of the building remained together in a group to the east, and the employees who evacuated from the west side of the building remained together in a group to the west (**Figure 18**). The groups had no documentation with them detailing who had been inside the facility at the time of the incident, and they therefore relied on memory when conducting head counts to determine whether anyone was remaining in the building.

Emergency responders arrived at the facility shortly after the explosion and began transporting injured workers to the hospital before head counts could be finalized. During this phase shortly after the incident, the maintenance technician was found inside the control room underneath rubble. Emergency responders extracted him from the rubble and transported him to the hospital, where he died from his injuries.

The rail operator was not immediately found due to a miscommunication during the incident response activities. The rail operator's name was pronounced "Kevin" (spelled "Kevens"), and there was also another employee at the facility named Kevin who worked in the Finance department. During attempts to conduct headcounts, a representative from one of the evacuated groups looking for the rail operator met with the other group and asked if they had seen "Kevin." Members of that group stated that they had seen Kevin in their group safe and accounted for, but they were referring to the employee named Kevin who worked in the Finance department. The two groups were unknowingly referring to the two different employees with names pronounced "Kevin." This miscommunication led to the rail operator remaining unidentified under the rubble inside the control room. Ten hours after the incident, he was found deceased inside the control room buried under debris[a] after his girlfriend alerted first responders that he was missing. Based on the extent of his injuries, the rail operator had likely died shortly after the incident [12].

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[a] The employee was retrieved from the control room at approximately 1:00 a.m.

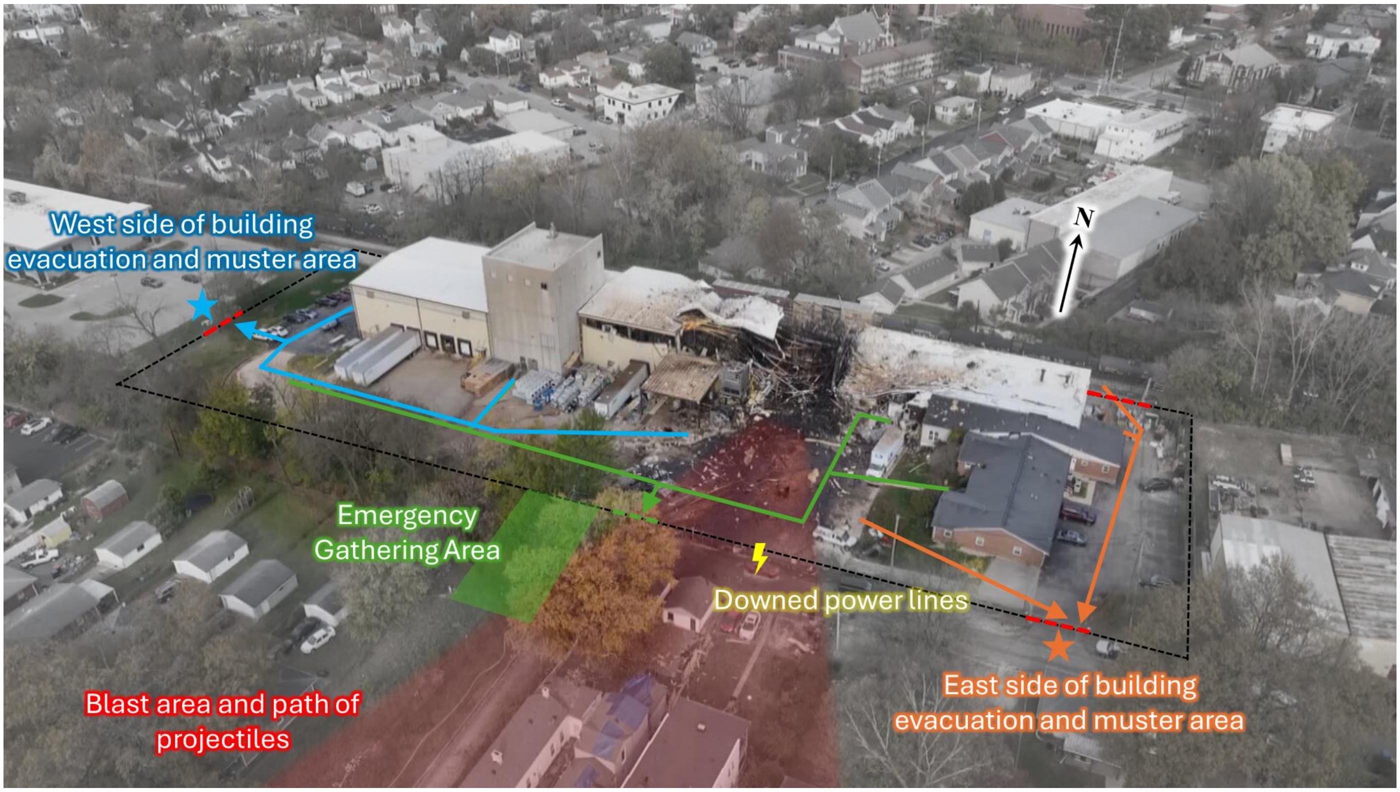

Figure 18. Depiction of the evacuation plan (green) versus the actual evacuation path taken by individuals at the facility (orange and blue). Personnel could not gather in emergency gathering area due to blast debris and a downed power line. (Credit: WAVE [13], annotated by CSB)

3 TECHNICAL ANALYSIS

The CSB confirmed in post-incident chemical reactivity testing that, at high temperatures inside enclosed vessels, the sugar ingredient of the Product 484 caramel coloring mixture undergoes a rapid exothermic decomposition reaction[a] that produces high pressure from the formation of non-condensable gases, primarily carbon dioxide (see *Section 3.1*).

On the day of the incident, the failure of the vent valve in the closed position (see *Section 3.2*) created abnormally high temperature and pressure inside Reactor 6 and initiated an uncontrolled exothermic decomposition reaction of the sugar ingredient. The cooling water system was unable to adequately remove the heat that was generated as the reaction accelerated (see *Section 3.3*) and was unable to stop the reaction.

The emergency pressure relief system installed on Reactor 6 was not adequately sized to relieve the gases and pressure produced by the decomposition reaction, and the pressure continued to increase until Reactor 6 overpressured and ruptured. To avoid the Reactor 6 rupture, the relief system would have to have been sized for the decomposition reaction scenario, which would have required additional relief capacity (see *Section 3.4*).

3.1 CHEMICAL REACTION ANALYSIS

Runaway (uncontrolled) reactions inside vessels can lead to catastrophic overpressures and explosions. The CSB has investigated multiple incidents where runaway reactions inside equipment have caused explosions and significant damage.[b] The Givaudan incident exhibited similarities to these prior incidents, including the use of a batch production process, a rapid and uncontrolled temperature and pressure rise, and an explosion that caused significant damage. To determine whether the materials in Reactor 6 experienced such a runaway reaction on the day of the incident, the CSB conducted laboratory reactivity tests on representative samples of the chemicals that were inside the reactor during the incident. These tests aimed, in essence, to re-create the November 2024 incident at a small laboratory scale. The results of these tests are presented below and are included in Appendix C.

The chemicals used inside Reactor 6 on the day of the incident—which included sugar,[c] phosphoric acid,[d] sodium hydroxide,[e] water, and an antifoam additive—were subjected to analytical tests, including Automatic Pressure Tracking Adiabatic[f] Calorimetry (APTAC) and Accelerating Rate Calorimetry (ARC). The tests aimed to determine the behavior of the chemicals when heated inside an enclosed vessel. Both the APTAC and ARC

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[a] An exothermic reaction is a reaction resulting in the evolution of heat.

[b] The CSB investigated the 1998 runaway reaction incident at the Morton International, Inc. facility in Paterson, New Jersey [39]; the 2003 runaway reaction incident at the Catalyst Systems, Inc. facility in Gnadenhutten, Ohio [40]; the 2007 runaway reaction incident at the T2 Laboratories, Inc. facility in Jacksonville, Florida [41]; and the 2020 runaway reaction incident at the Optima Belle, LLC facility in Belle, West Virginia [18].

[c] Givaudan used a sugar syrup called invert sugar, which was a mixture of glucose, fructose, sucrose, and water.

[d] Phosphoric acid and sodium hydroxide are added as catalysts to help initiate the caramel color reaction mechanism.

[e] Sodium hydroxide is also used to control the pH during the caramel color process.

[f] In an adiabatic process, heat does not leave or enter the system from the environment.

tests were conducted using raw materials collected by the CSB from the Louisville facility,[a] which were representative of the materials in Reactor 6 at the time of the incident.

Both APTAC and ARC are laboratory testing methods in which materials in an enclosed reaction vessel are incrementally heated until an exotherm is detected.[b] An exotherm is an event in which test materials increase in temperature due to the evolution of heat resulting from a chemical reaction. In APTAC and ARC tests, after an exotherm is detected, the temperature and pressure are measured until the reaction is complete [14] [15]. The incremental heating, exotherm detection, and exotherm measurement processes then continue until testing is ended.

The APTAC temperature and pressure versus time results for the mixture inside Reactor 6 at the time of the incident are shown in **Figure 19**. The test identified three separate exotherms. All of the exotherms occurred or were initiated at conditions within the reactor's normal operating range and limits, as shown by the process temperature set point (300°F) and pressure safe operating limit designations. The first two exotherms coincided with the injection of the phosphoric acid, sodium hydroxide, water, and antifoam into the reaction vessel. The third, and largest, exotherm started when the materials were heated to a temperature of 243°F. During that exotherm, the materials experienced a temperature rise of 284°F and generated a maximum pressure of 1,509 psig. These testing results are consistent with the pressure and temperature data collected during the Givaudan incident (**Figure 11**), which indicate that an exotherm was initiated below Reactor 6's 300°F set point and coincided with a rapid pressure increase that ruptured the reactor.

Gas evolved from the materials during the laboratory test, contributing to the observed increase in pressure. After the mixture was cooled to room temperature, the non-condensable gases produced had a pressure of 391 psig. The generated non-condensable gases were collected, tested, and found to be predominantly carbon dioxide.

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[a] The CSB collected the invert sugar, phosphoric acid, sodium hydroxide, and antifoam used in the testing from the Louisville facility. The testing laboratory supplied the water used in the tests.

[b] Both APTAC and ARC are adiabatic calorimeters that use a Heat-Wait-Search (HWS) methodology. HWS is a sequence where the sample is heated to a specified temperature, allowed to stabilize at the temperature, and monitored to observe any increase in temperature resulting from an exothermic reaction. If no exotherm is detected, the test proceeds to the next temperature step. Upon detection of an exotherm, the equipment changes from HWS mode to adiabatic tracking while the sample is monitored until heat is no longer being generated by the reaction. When the temperature has stabilized after an exotherm event, the test equipment will return to the HWS sequence until an exotherm is detected or the maximum temperature or pressure of the test method has been exceeded.

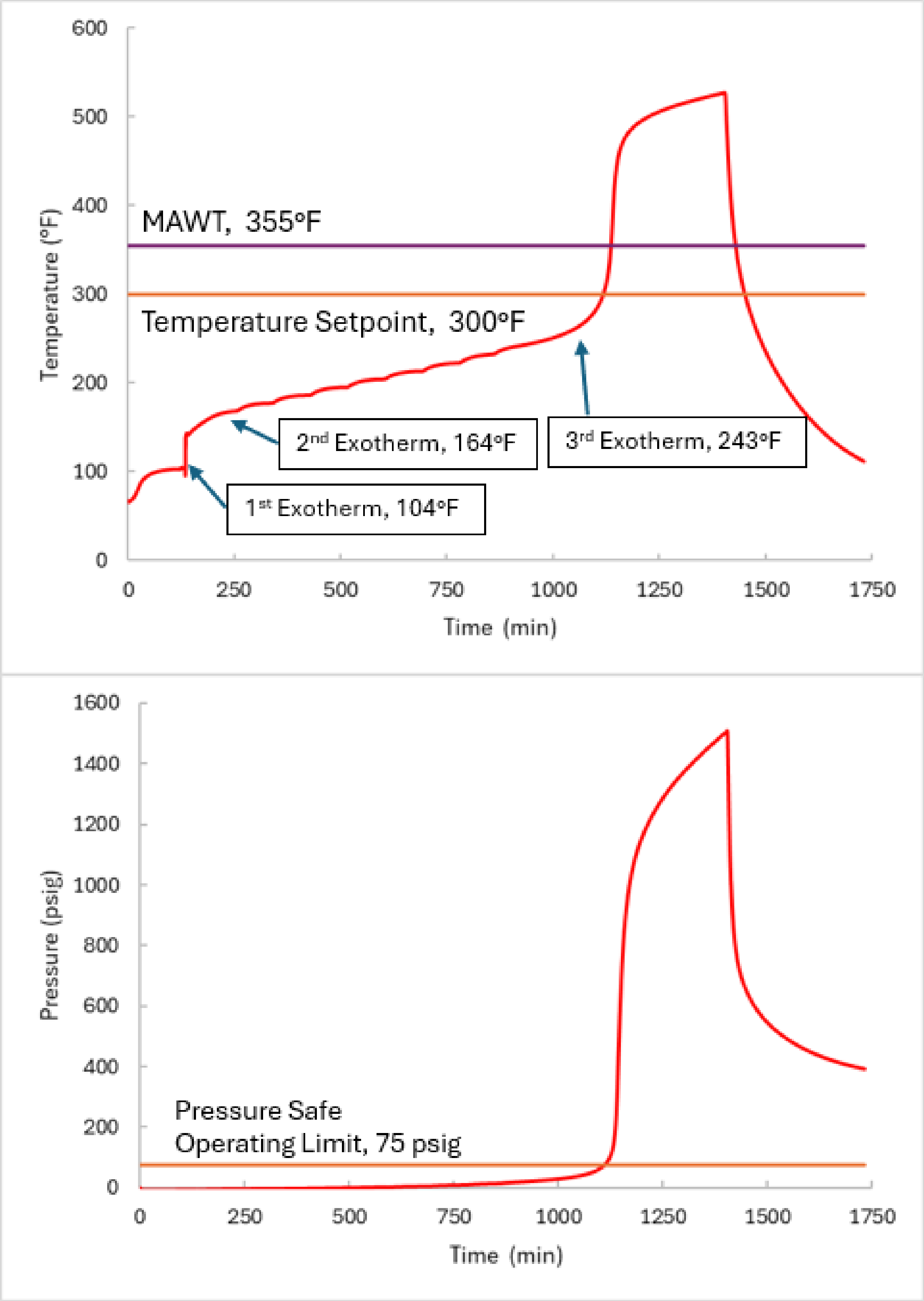

Figure 19. APTAC temperature and pressure versus time results for Reactor 6 mixture. The Reactor 6 MAWT, temperature set point on the day of the incident, and the pressure safe operating limit, are indicated. (Credit: CSB)

Additional reactivity tests were conducted on both the Reactor 6 mixture and the sugar ingredient alone using ARC[a] to determine the extent to which each might have contributed to the runaway reaction in the reactor. The ARC temperature and pressure versus time results from both tests are shown in **Figure 20**. Both tests identified major exotherms[b] beginning within the normal operating limits of the reactor, which generated high temperature and high pressure. Gas evolved from the materials during the tests, contributing to the observed pressure rise in each test. After the samples in each test were cooled, the non-condensable gas pressures were 490 psig (for the reactor mixture) and 419 psig (for the sugar ingredient alone). Similar to the previous calorimetry testing performed on the Reactor 6 mixture, the gas from each test was sampled and also determined to be predominantly carbon dioxide.

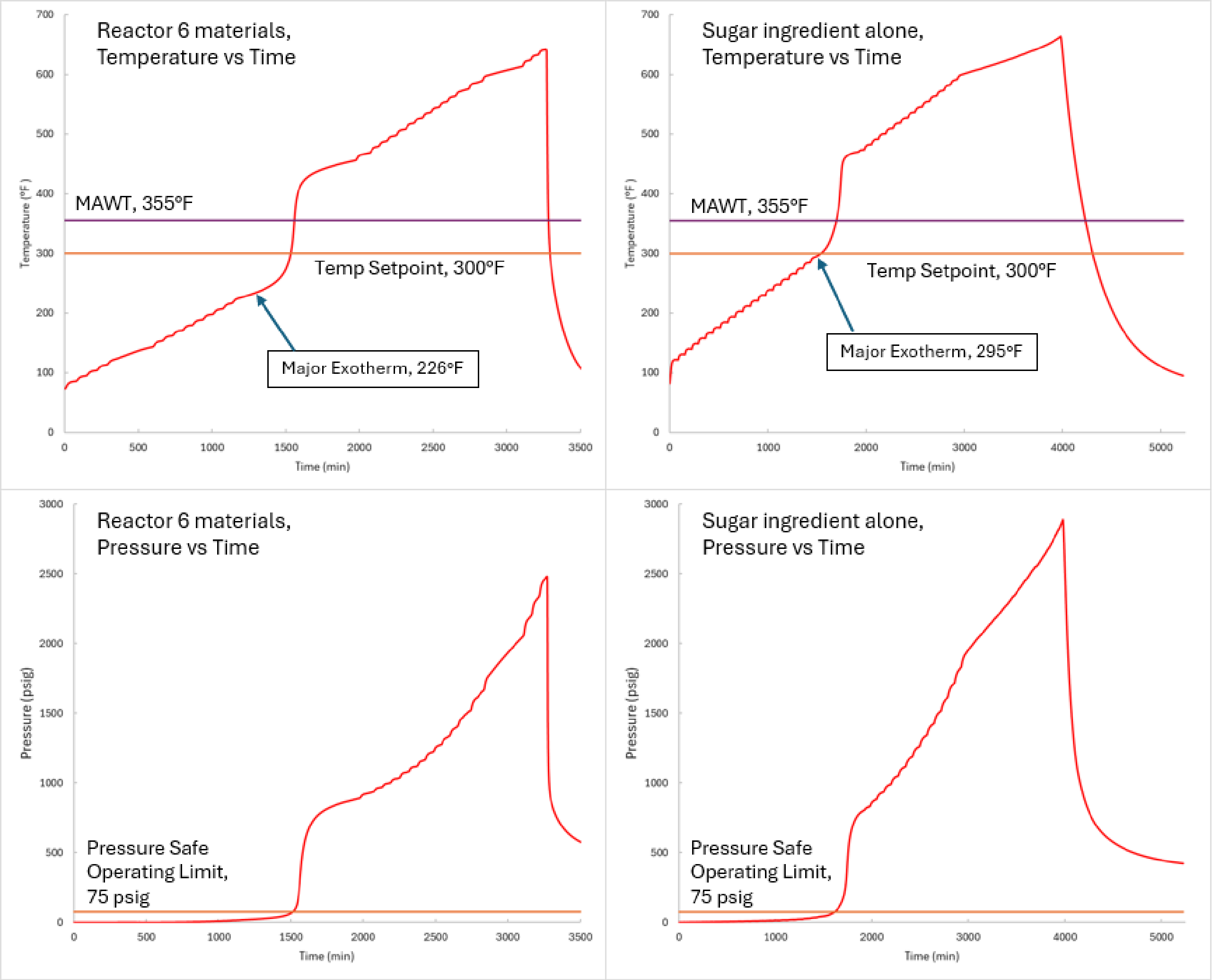

Figure 20. ARC temperature and pressure versus time test results for reactor mixture and sugar ingredient alone. The Reactor 6 MAWT, temperature set point on the day of the incident, and the pressure safe operating limit, are indicated. (Credit: CSB)

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[a] The primary difference between ARC and APTAC is that APTAC has a larger sample size and lower thermal inertia [14], which makes it useful for analyzing large vessels like a batch reactor. ARC testing achieves similar results to APTAC but requires scale-up calculations [15].

[b] Other small exotherms occurred during these tests and are not indicated in the figure.

The results of the chemical reactivity testing show that even within Reactor 6's normal operating temperature and pressure range, both the caramel coloring ingredient mixture as well as the sugar ingredient without the other recipe ingredients could experience a hazardous reaction, producing dangerously high temperatures and pressures far beyond the reactor's safe limits.

In the test of the sugar ingredient only, the production of carbon dioxide gas was the result of the decomposition of the sugar, as no other chemicals were present. Because carbon dioxide was generated in tests of both the caramel coloring recipe and the sugar ingredient without the other recipe ingredients, and because sugar was the primary carbon-containing component in the caramel coloring recipe,[a] the carbon dioxide gas generated in the tests must have been produced by the reaction (decomposition) of the sugar. Therefore, even in the mixture, the sugar ingredient was the component that reacted (decomposed) to cause the observed temperature and pressure increases. The other mixture materials were not required for the runaway reaction that occurred on November 12, 2024. The CSB's analysis of the likely reaction sequence that led to the incident is described in Appendix D.

The CSB concludes that on the day of the incident, the sugar ingredient of the Reactor 6 caramel coloring mixture underwent an uncontrolled (runaway) exothermic (heat-producing) decomposition reaction that produced high temperature and high pressure—from the generation and heating of non-condensable gases—that caused Reactor 6 to catastrophically rupture.

The CSB also analyzed process data to determine whether the Product 484 batch instruction was followed. The CSB found that operators followed the batch instruction steps as-written, with the exception that they also added water into Reactor 6 before the batch instruction specified to do so. The CSB analyzed six other likely Product 484 batches[b] and found that water was similarly added to the other batches at similar batch sequence steps. Additionally, the other Product 484 batches did not exceed 300°F or 12.5 psig at the batch step at which the November 12, 2024 incident occurred. Based on both the chemical reactivity testing presented above and the comparison with other Product 484 batches, the additional water fed into Reactor 6 was not causal to the incident.

The CSB concludes that operators followed the Product 484 batch instruction and implemented typical Product 484 manufacturing practices on the day of the incident. There were no abnormal materials, abnormal quantities of materials, or abnormal feed sequences that were causal to the incident.

As will be discussed below, the uncontrolled decomposition reaction of the sugar was initiated on the day of the incident when the vent valve failed in the closed position, creating higher-than-typical temperatures in Reactor 6 at that stage in the Product 484 manufacturing process.

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[a] In addition to sugar, Reactor 6 contained water (H_2O), sodium hydroxide ($NaOH$), phosphoric acid (H_3PO_4), and an antifoam ingredient. While the antifoam ingredient does contain carbon, the amount of antifoam in the reactor mixture was not sufficient to generate significant carbon dioxide gas.

[b] Givaudan maintained a production schedule for each of its reactors at the Louisville facility. The company periodically deviated from the planned schedule, however, and did not clearly document the actual product manufactured in each reactor each day. The CSB therefore identified likely Product 484 batches by analyzing process data to identify batches where material additions and process set points aligned with the Product 484 batch instruction.

3.2 REACTOR 6 PRESSURE CONTROL (VENT VALVE)

During normal operation, the evaporation and venting of water vapor through Reactor 6's 6-inch vent line aid in controlling the reactor temperature and, consequently, the reaction rate of the typical caramelization reaction described in Appendix D. As discussed in *Section 2*, it was determined that, from 2:39 p.m. until Reactor 6 exploded at 2:57 p.m. —a period of approximately 18 minutes— the vent valve was in the closed position despite being commanded by the PLC to be fully open. This vent valve closure prevented heat from being removed from Reactor 6 by the cooling effect of the evaporation and venting of water vapor.[a] As a result, the temperature of Reactor 6 increased at a faster-than-typical rate, accelerating the caramelization reaction in an uncontrolled manner. The closure of the vent valve, therefore, was a key event that triggered the accelerated decomposition reaction that led to the incident.

Reactor 6's vent valve was a 6-inch ball valve (control valve) equipped with a pneumatic[b] actuator. A positioner was installed on the actuator to control the actuator's position (**Figure 21**).

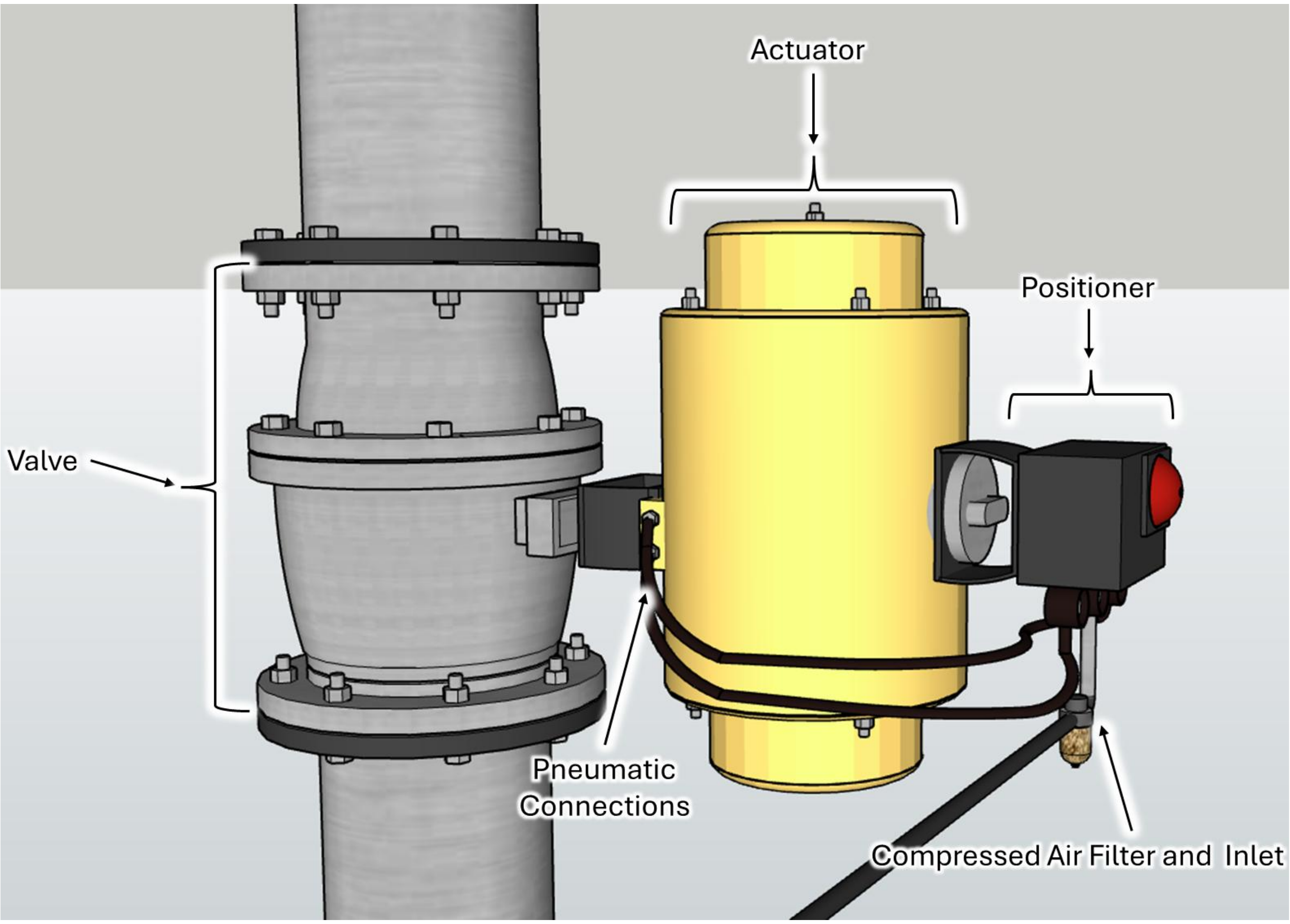

Figure 21. Depiction of the Reactor 6 vent valve, actuator, and positioner (Credit: CSB)

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[a] During the initial period of the vent closure, for approximately 8 minutes, the reactor was still being heated. Cooling water was not fed to the internal coils until approximately 9 minutes after the vent valve closed, at which time the decomposition reaction had already begun to accelerate.

[b] A pneumatic device is a device that contains or is operated by pressurized air or gas.

As described below, the CSB evaluated each of the three vent valve components (vent valve, actuator, and positioner) in an effort to determine why the Reactor 6 vent valve was in the closed position when it was commanded to open. As will be described, there is insufficient evidence to determine why the Reactor 6 vent valve failed to open as it was commanded. No mechanical deformities or obstructions were identified in the valve. Additionally, testing data from the similar Reactor 5 vent valve and actuator assembly indicate that the Reactor 6 actuator was appropriately sized for the application. Further, the positioner was not recovered after the incident and, as a result, could not be tested or analyzed to determine whether it contributed to the vent valve failure.

The sections below describe what the CSB was able to determine about each of the three control valve components and the key evidence collected.

Valve

Surveillance footage indicates that the Reactor 6 vent valve was in the closed position leading up to the incident (*Section 2.2*). The vent valve was recovered after the incident, still connected to the vent piping (**Figure 22**), and post-incident inspection confirmed that the valve was in the closed position (**Figure 23**).

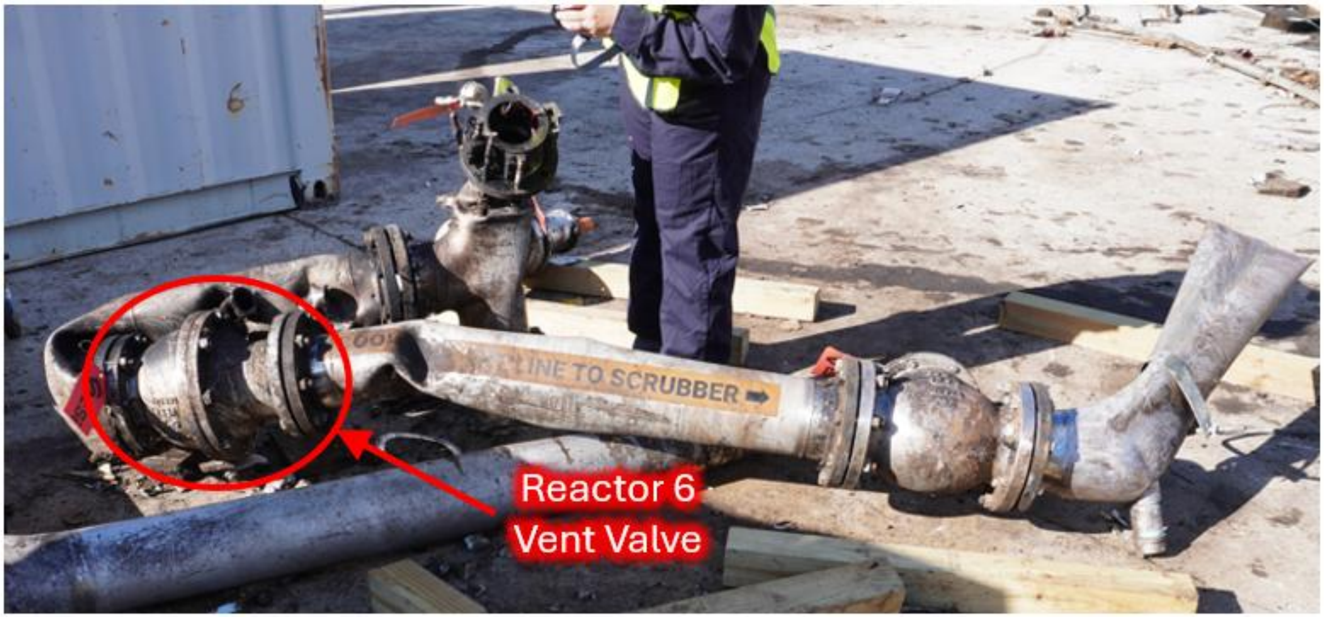
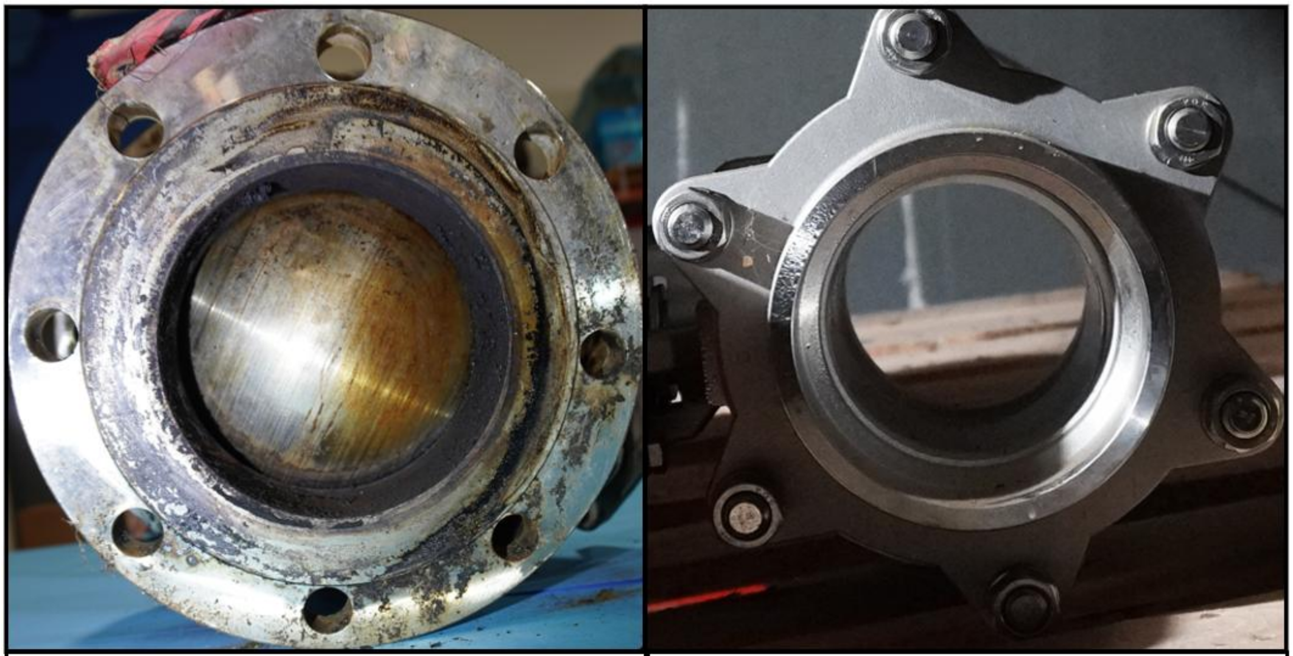


Figure 22. Reactor 6 vent valve attached to vent piping. Photo was captured after piping segment had been manually disconnected and relocated outside the building after the incident. (Credit: CSB)



Reactor 6 vent valve (closed)

Photo of an Example Ball Valve in Open Position

Figure 23. Photo of the recovered Reactor 6 vent valve in the closed position and an example ball valve in the open position. (Credit: CSB)

Because the valve stem was severely damaged by the explosion, the CSB was unable to perform a function test of the valve to identify operational issues or other valve failure scenarios. Instead, the valve was disassembled. Inspection of the valve's components did not identify any mechanical deformities or obstructions that might have hindered the valve's function prior to the explosion. Additionally, while some residual, dried caramel coloring product was observed in the valve, it did not appear to be sufficient to prevent the valve from opening from the available force supplied by the actuator springs.

Actuator

The Reactor 6 vent valve pneumatic actuator controlled the vent valve position. Varying air pressure inside the actuator's internal chamber was used to modulate the position of the valve (see sidebar below). The pneumatic actuator was configured to move to the open position ("fail open") in the event of a compressed air loss.

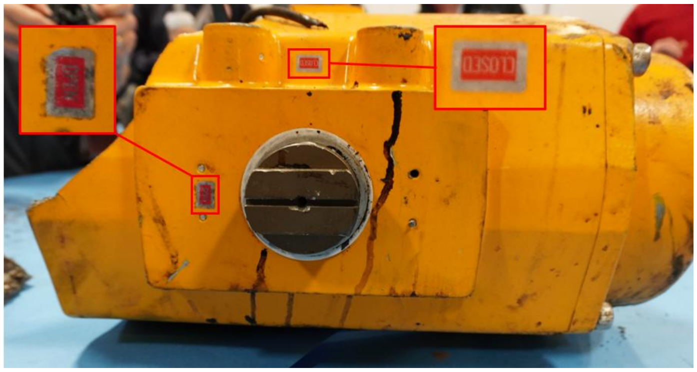


Figure 24. Recovered pneumatic actuator from Reactor 6 vent valve (pinion indicator labels highlighted and enlarged). (Credit: CSB)

The Reactor 6 vent valve pneumatic actuator was located and recovered after the incident. The actuator was found disconnected from the vent valve, outside the building, approximately 165 feet from its original location, with a fractured case and missing internal springs on one side. Although damaged, the actuator was recovered in the open configuration, as shown by the position of the pinion indicator (**Figure 24**). The sticker to the left of the pinion is labeled "OPEN," and the sticker above the pinion is labeled

“CLOSED” with the pinion indicator pointing to “OPEN.” When the actuator physically separated from the valve and positioner during the explosion, the internal springs may have returned the actuator to the open position.

Reactor 6 “Fail Open” Pneumatic Actuator Details

The pneumatic actuator installed on Reactor 6, which was configured to fail open, consists of the following parts within the actuator housing: a pinion, pistons, an air chamber, and springs. As illustrated in **Figure 25**, when air is added to the air chamber, the actuator pistons compress the internal springs and rotate the pinion in the “A” direction. As the air is released from the air chamber, the springs will return the pistons to the de-energized state and rotate the pinion in the “B” direction.

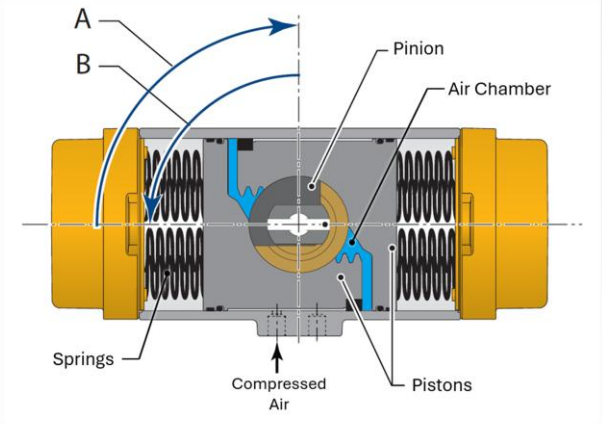


Figure 25. Internal view of a fail-open pneumatic actuator in the de-energized state (valve open) with parts labeled (Credit: Elomatic, annotated by CSB)

For an actuator configured to fail open, the “A” direction (air chamber is pressurized) closes the valve (**Figure 26**), and the “B” direction (air chamber is not pressurized) opens the valve (**Figure 25**).

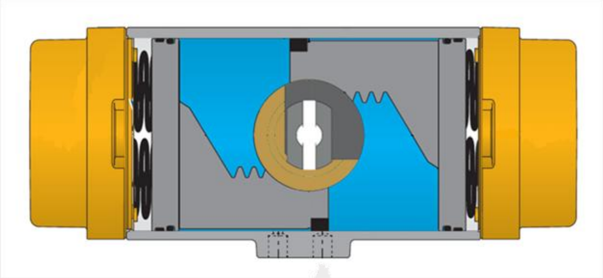


Figure 26. Internal view of a fail-open pneumatic actuator in the energized state (valve closed). (Credit: Elomatic, modified by CSB)

Choosing a fail-open or fail-closed actuator allows the valve to be moved to a predetermined safe position in the event of a loss of compressed air.

Due to the extent of the damage sustained by the Reactor 6 vent valve actuator in the explosion, the CSB was unable to function test the actuator. The CSB, however, was able to test the vent valve and actuator assembly from Reactor 5, which used the same valve model and a functionally equivalent actuator model[a] as was installed on Reactor 6. The Reactor 5 actuator was also configured to fail open upon a loss of air pressure inside its internal chamber. During testing, with the vent valve in the open position, compressed air was supplied to the Reactor 5 actuator, and the pressure was gradually increased to determine the minimum pressure required to close the valve. Pressure applied to the actuator was then gradually decreased to determine the point at which the actuator springs would open the valve. Across five test cycles, the Reactor 5 actuator closed the valve with a supplied air pressure of 45–56 psig. The internal springs then opened the valve when the air pressure was reduced below 32–34

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[a] The Reactor 5 and Reactor 6 vent valve actuators were nearly identical models. The only difference between the actuator models was related to the “limit stops” design, which are the mechanical stopping points at which the actuator stops its motion when the valve reaches either its fully open or fully closed position. The Reactor 5 actuator was equipped with adjustable limit stops for both the open and closed valve positions. The Reactor 6 actuator was equipped with an adjustable limit stop for only the open position. These design differences would not have affected the actuators’ torque output or the internal chamber air pressure required to function the valves.

psig.[a] Testing of the Reactor 5 vent valve and actuator assembly confirmed that the actuator was able to move the vent valve to the open and closed positions.

Based on the testing of the Reactor 5 vent valve and actuator, it appears that the Reactor 6 actuator was correctly sized to operate the Reactor 6 vent valve.

Documents and interviews with personnel indicate that the Louisville facility's compressed air was maintained at 120 psig, but was regulated to a lower pressure for operating the actuators. Givaudan's records and data obtained by the CSB did not indicate this lower pressure set point. A reduction in plant air pressure below 30 psig or a loss of compressed air to the actuator should result in the opening of the vent valve, as opposed to the complete closure of the vent valve experienced during the incident. Additionally, a PLC command to open the vent valve, as occurred leading to the incident, should also reduce the air pressure inside the actuator chamber to allow the vent valve to open. The PLC commands to open the vent valve would have been communicated to the positioner installed on the actuator. The positioner is discussed below.

Positioner

A positioner (**Figure 27**) is a device that receives an electronic control signal from the PLC system and modulates the air pressure supplied to the actuator to control the valve position.

The positioner installed on the Reactor 6 vent valve actuator was not recovered after the incident. The positioner installed on the Reactor 5 vent valve actuator was also not recovered after the incident. As a result, the CSB was unable to test potential positioner scenarios that might have contributed to the Reactor 6 vent valve remaining closed when it was commanded to open, such as communication failures to/from the positioner or a mechanical failure that could prevent air from being released from the actuator chamber, thereby holding the valve in the closed position.

Figure 27. Example of a valve positioner.

Conclusions

The CSB concludes that when the Reactor 6 vent valve (pressure control valve) failed in the closed position 18 minutes before the Reactor 6 rupture, an important mechanism for controlling the reactor temperature by evaporating and venting water vapor was lost. As a result of the valve failure, the typically controlled exothermic sugar decomposition reaction accelerated.

The CSB also concludes that the Reactor 6 vent valve failure could have resulted from a malfunction in any of the three control valve components: the valve, the actuator, or the positioner. However, there is insufficient evidence to determine why the Reactor 6 vent valve failed to function correctly during the 18 minutes before Reactor 6 ruptured. No mechanical deformities or obstructions were identified in the valve, the actuator appears

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[a] Testing of the Reactor 5 vent valve and actuator was performed with 0 psig differential pressure across the valve. During normal operations, there could be a differential pressure up to 75 psig, which would increase the actuator torque requirements for valve opening. The CSB calculated a 2.25 psig difference in air pressure to account for additional torque. In the case of a fail-open actuator, the additional torque would delay the valve opening until the internal air pressure was 2.25 psig lower than observed in the testing.

to have been appropriately sized for the application but could not be tested due to damage sustained in the explosion, and the positioner was not recovered after the incident and could not be analyzed or tested.

3.3 REACTOR 6 TEMPERATURE CONTROL

The Reactor 6 temperature was controlled by either steam or cooling water flowing through coils mounted to the inside wall of the reactor. The PLC would automatically open valves to apply either steam or cooling water to the coils to maintain the desired temperature. When the loss of vent control happened (*Section 3.2*), Reactor 6 was actively being heated by steam to raise the reactor temperature to the 300°F set point. For approximately 8 minutes, steam continued to be applied to the coils while the vent valve was in the closed position, until the temperature in the reactor exceeded the 300°F set point.[a]

After the temperature inside Reactor 6 exceeded the 300°F set point, the steam fed to the coils automatically shut off, and at 305°F (2:48 p.m.), the PLC system called for cooling water to be applied to the coils. The recorded process data shows that once cooling water was applied to the coils, the rate of temperature rise inside Reactor 6 was temporarily reduced before it again began to rise (**Figure 28**). This continued temperature rise indicates that the cooling water system was unable to adequately remove the heat generated by the accelerating exothermic decomposition reaction. The CSB was not provided with any documents indicating that the Reactor 6 temperature control system was designed or engineered to remove the quantity of heat produced by the accelerating exothermic reaction.

The temperature continued to rise for 9 more minutes until Reactor 6 ruptured at 2:57 p.m. The steam applied to the reactor coils, after the vent valve was closed, may have contributed to the acceleration of the decomposition reaction.

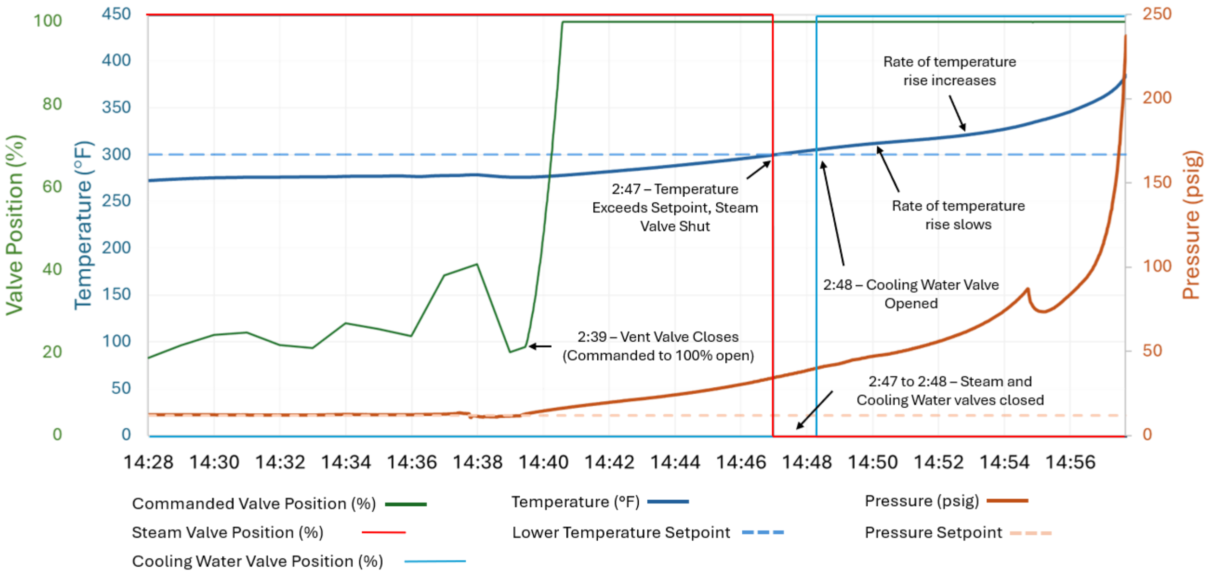

Figure 28. Reactor 6 temperature trend with valve commands on the day of the incident (Credit: CSB)

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[a] When the Reactor 6 temperature exceeded the 300°F temperature set point, the internal pressure was approximately 34 psig, which was 22 psig above the pressure set point of 12 psig.

The CSB concludes that, although the Reactor 6 cooling water system was activated 9 minutes before the incident in an attempt to reduce the Reactor 6 temperature, the cooling water system was unable to adequately remove the heat generated by the accelerating exothermic decomposition reaction. As a result of this inability to adequately remove heat from the reactor, the Reactor 6 temperature continued to rise, and the exothermic decomposition reaction continued to accelerate until Reactor 6 ruptured.

3.4 RELIEF SYSTEM DESIGN

An emergency pressure relief system is a layer of protection often considered the last line of defense against equipment rupture in high-pressure process upsets. When processes are operating correctly, system pressure stays under control and within the equipment's design limits. Process upsets, such as undesired chemical reactions, can cause the pressure to exceed equipment design limits. When these scenarios occur, the emergency pressure relief system must lower the system pressure. Otherwise, a catastrophic equipment rupture could occur, harming people or propelling equipment fragments that could impact other critical equipment, escalating the incident's consequences.

Pressure vessels installed in the Commonwealth of Kentucky are required to adhere to the ASME Boiler and Pressure Vessel Code (BPVC) requirements for overpressure protection.[a] These code requirements state that the owner/operator of the vessel has a responsibility to make a "determination of all potential overpressure scenarios and of the method of overpressure protection used to mitigate each scenario."[b] In interviews, Louisville facility personnel stated that the relief system design for Reactor 6 was based on that of Reactor 2. The facility did not possess any documentation detailing the design basis for the Reactor 2 emergency pressure relief system.

The pressure relief system installed on Reactor 6 consisted of a rupture disc and a pressure relief valve installed in series. The rupture disc was a 4-inch disc (12.56 square inch area), constructed of 316 stainless steel with a burst rating of 75 psig at 355°F. The pressure relief valve, set to relieve pressure at 75 psig, had a 4-inch inlet and a 6-inch outlet, with a 4.186-square-inch orifice size (API designation 4M6).[c] The pressure relief valve's outlet was connected to a 6-inch stainless steel pipe with an equivalent length[d] of 184 feet. This relief piping was routed to a 4,500-gallon catch tank, which vented to the atmosphere through the plant scrubber system, as shown in **Figure 29**.

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[a] Kentucky Administrative Regulations (KAR) Title 815, Chapter 015, Regulation 025 *New installations, general design, construction, and inspection criteria for boilers, pressure vessels, and pressure piping*

[b] 2021 ASME BPVC Section VIII, Division 1, Part 2, 2.2(a)(2)

[c] API denotes the size of a pressure relief valve orifice with a letter designation. The Reactor 6 pressure relief valve had an API "M" orifice designation.

[d] Equivalent length of a pipe system is the length of a similarly sized straight pipe, without elbows or other fittings, that would produce the same pressure drop for a given flow rate.

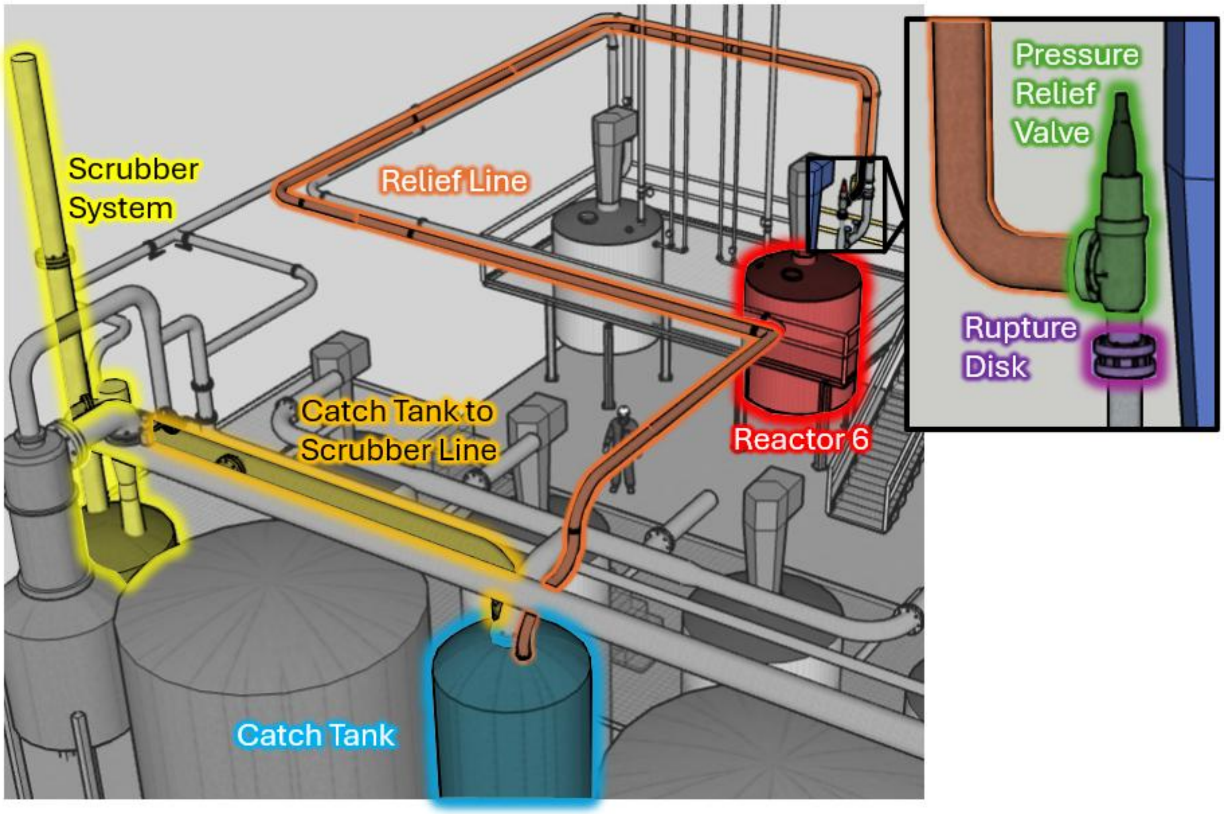

Figure 29. Reactor 6 emergency pressure relief equipment and piping (Credit: CSB)

Recorded process data indicates that the rupture disc and pressure relief valve activated at 2:54 p.m., and the pressure inside Reactor 6 temporarily decreased before rising again. The pressure continued to rise until Reactor 6 ruptured with a final recorded pressure of 237 psig, more than three times the MAWP of 75 psig. Evidence indicates that the relief system (rupture disc and pressure relief valve) functioned as designed (see process data in **Figure 11** and the relief system component testing information in *Section 3.4.1* below). The relief system, however, was undersized for the sugar decomposition reaction that occurred on the day of the incident, as evidenced by the Reactor 6 rupture, and was unable to adequately relieve the gas and pressure generated.

3.4.1 TESTING OF RELIEF SYSTEM COMPONENTS

The Reactor 6 emergency pressure relief system components (rupture disc and pressure relief valve) were recovered after the incident. The rupture disc was found fully open, which is the expected position after activation. **Figure 30** shows the rupture disc as found.

Figure 30. Reactor 6 rupture disc as found post-incident, fully open. (Credit: CSB)

The CSB conducted testing of the recovered Reactor 6 pressure relief valve to determine whether it would activate at the correct set pressure as designated in the most recent service documents. The CSB conducted a "pop test" (**Figure 31**), which involved applying pressure to the closed pressure relief valve to determine the pressure at which it opened. The Reactor 6 pressure relief valve, however, sustained damage during the explosion, and as a result, the valve seat could not hold pressure to conduct the test. The CSB then disassembled the valve to inspect its internal components and found no obvious signs of malfunction.

Figure 31. Reactor 6 pressure relief valve set up on the testing stand for pop testing. (Credit: CSB)

Reactor 5 was equipped with the same model 4M6-sized pressure relief valve installed on Reactor 6 and was similarly set to a 75 psig set pressure. The CSB pop-tested the Reactor 5 pressure relief valve. The Reactor 5 pressure relief valve held pressure and opened at 77 psig, which was within the acceptable tolerance range.

The CSB concludes that the Reactor 6 emergency pressure relief system, consisting of a rupture disc and pressure relief valve, did not show any signs of mechanical malfunction that would have prevented it from operating on the day of the incident.

3.4.2 REQUIRED RELIEF SYSTEM DESIGN TO PREVENT REACTOR 6 RUPTURE

The CSB consulted with an external industry expert on relief system design and commissioned a study to model potential relief systems capable of providing the necessary protection against the exothermic decomposition reaction observed during the incident.

The modeling, based on actual incident data and post-incident laboratory analysis, determined that if a pressure relief valve was used to provide the required overpressure protection, a relief area of at least 16.74 square inches would be necessary to meet code compliance. This relief area could be satisfied with an API-designated 6R10 pressure relief valve. With a relief capacity over four times that of the 4M6 pressure relief valve installed on Reactor 6, a 6R10 pressure relief valve has a 6-inch-diameter inlet, a 10-inch-diameter outlet, and an 18.6-square-inch orifice. Installation of the larger pressure relief valve would also require a 6-inch rupture disc and increasing the relief line diameter from 6 inches to 10 inches.

The relief study determined that, alternatively, the 4M6 pressure relief valve could have been removed, and that the 4-inch rupture disc alone would have provided the necessary relief capacity to prevent the rupture of Reactor 6.

The CSB concludes that the Reactor 6 emergency pressure relief system functioned as designed but was undersized for the accelerated sugar decomposition reaction that occurred on the day of the incident. As a result of the emergency pressure relief system's inadequate size, the gases and pressure generated by the accelerated decomposition reaction could not be adequately relieved from the reactor, and the reactor's internal pressure continued to rise from the formation and heating of the gases until Reactor 6 ruptured from the runaway reaction. To prevent the Reactor 6 rupture, the existing emergency pressure relief system (pressure relief valve with rupture disc) would have needed to be four times larger. Alternatively, calculations and modeling software show that a 4-inch rupture disc alone should have provided the necessary relief capacity to prevent the rupture of Reactor 6.

4 SAFETY ISSUES

The following sections discuss the safety issues contributing to the incident, which include:

- Understanding Chemical Reaction Hazards
- Commitment to Managing Process Safety
- Safe Operating Limits
- Facility Siting
- Regulatory Coverage of Reactive Hazards

Appendix A contains the accident map (AcciMap), which provides a graphical analysis of this incident.

4.1 UNDERSTANDING CHEMICAL REACTION HAZARDS

D.D. Williamson, and subsequently Givaudan, did not understand the reaction potential of the Product 484 sugar ingredient, which contributed to both an undersized Reactor 6 emergency pressure relief system and confusion on the day of the incident regarding the reason for the increasing Reactor 6 pressure. As discussed in this section, the companies' lack of knowledge of the reactive hazards stemmed from their incomplete investigation of caramel coloring ingredients' reaction potential, a lack of industry guidance related to the safe manufacture of caramel coloring, and sugar ingredient safety data sheets (SDSs) that did not warn of the decomposition reaction potential.

KEY LESSON

Chemical facilities should analyze any event in which their chemicals or processes produce unanticipated temperature or pressure changes. Such events could indicate that the chemicals underwent a chemical reaction that must be understood to allow for the proper and safe design of equipment. Comprehensive reactivity testing (for example, calorimetry testing) on ingredients and final products can provide important information on temperature and pressure behavior during chemical reactions, which is essential information when sizing emergency pressure relief systems to protect equipment, workers, and communities from reactive hazards.

4.1.1 INADEQUATE REACTIVITY ANALYSIS

The 2012 chemical reactivity testing of Product 034 ingredients revealed that when the ingredients were heated in an enclosed vessel, they experienced a rapid rise in temperature and pressure and formed non-condensable gases (*Section 1.8.2*). Neither D.D. Williamson nor Givaudan further investigated the 2012 chemical reactivity testing results to determine the reaction mechanism or investigate whether other products could behave similarly when heated. Instead, D.D. Williamson stopped investigating the reaction and assumed that only Product 034—which the company believed was its most hazardous product because it generated the most heat during the manufacturing process—could react in that manner. Additionally, D.D. Williamson did not choose to conduct testing beyond the minimum recommended in the 2008 HAZOP, and required by the EPA Consent Decree, even though the 2012 testing that was conducted did not provide clarity relating to the specific reaction mechanism(s) that led to the rapid temperature and pressure increase. Understanding the reaction mechanism(s) would have required additional reactivity testing and analysis.

For instance, had D.D. Williamson investigated the results of the 2012 Product 034 reactivity testing further and conducted additional reactivity testing of other products or individual ingredients, it might have discovered that the sugar ingredient was self-heating and decomposing to produce the generated gases. D.D. Williamson then might have realized that most, if not all, of its sugar ingredients could similarly react when heated in an enclosed vessel. This discovery might have led the facility to equip all of its reactors with emergency pressure relief systems designed for these accelerated decomposition reactions. As will be discussed in *Section 4.2*, the Louisville facility's inadequate management of process safety contributed to personnel not taking needed actions to understand the reactive potential of the sugar ingredients.

The CSB concludes that further analysis of the 2012 Product 034 reactivity testing results and additional reactivity testing could have led D.D. Williamson to discover that the generation of high temperature and pressure in the 2012 testing was caused by the self-heating and decomposition of Product 034's sugar ingredient. This discovery could have led the company to realize that many of its caramel coloring products' sugar ingredients could have similar reactivity potential. This, in turn, could have led the company to implement equipment design changes that could have prevented the 2024 incident, including equipping Reactor 6 with an emergency pressure relief system specifically designed for the sugar decomposition reaction scenario. However, D.D. Williamson did not choose to conduct additional reactivity testing beyond the minimum that the EPA Consent Decree required.

The CSB recommends that Givaudan contract a third party to analyze the reactivity of the sugar ingredients in the caramel coloring product manufacturing process by, at a minimum:

a. Conducting calorimetry testing on at least one representative recipe for all caramel coloring product types to determine their temperature and pressure behavior upon heating.

b. Testing the composition of any produced non-condensable gases.

Maintain this information for future equipment design efforts and hazard analyses. (*2024-06-I-KY-R1*)

4.1.2 INDUSTRY GUIDANCE

Trade associations play an essential role in sharing important safety findings with their members. The International Technical Caramel Association (ITCA) is a trade association composed of caramel color producers from around the world, of which Givaudan is an active member. The ITCA focuses on:

> the stewardship and safety of caramel colors and promoting the development of their production, processing, and use.

The ITCA publishes information on the food safety of caramel color products; however, it does not currently provide its members with information on how to safely manufacture caramel coloring or warn of the reactive hazards associated with the caramel coloring sugar ingredients. The CSB has identified no other industry trade group that provides safety guidance on caramel color manufacturing. A publication addressing the reactive hazards associated with caramel coloring sugar ingredients could have helped D.D. Williamson and Givaudan realize the potential for the accelerating sugar decomposition reaction and the need to implement safeguards, including installing a larger emergency pressure relief system designed for the reaction scenario, to prevent the incident.

The CSB concludes that there is no industry guidance specifically for the safe manufacturing of caramel coloring products. The development of such guidance detailing the known hazards of caramel color manufacturing and the need for appropriately sized emergency pressure relief systems to safely vent pressure and gases that could be produced by sugar ingredient decomposition reactions can help prevent future catastrophic vessel overpressure incidents.

The CSB recommends that ITCA publish a technical safety bulletin for safe caramel coloring manufacturing, which will be discussed further in *Section 4.2.4*.

4.1.3 SAFETY DATA SHEETS

SDSs provide important information about the hazards associated with specific materials. OSHA's Hazard Communication Standard[a] requires all manufacturers, distributors, or importers of hazardous materials to provide SDSs with a consistent format, composed of 16 sections. Sections 7, 9, and 10 of an SDS could (and should) provide critical information about potential hazardous reactions. Section 7 details instructions for safe handling and storage of a material, Section 9 details information about the chemical and physical properties of a substance, including decomposition temperature, and Section 10 contains information regarding the reactivity and stability of a substance.

The Louisville facility purchased both invert sugar and corn syrup as sugar ingredients for many caramel coloring products. Product 484—the product being manufactured in Reactor 6 at the time of the November 2024 incident—used invert sugar as its sugar ingredient. The SDS provided by the invert sugar manufacturer did not warn of its reactivity hazards, as shown in Section 10 of the SDS in **Figure 32**.

KEY LESSON

Safety data sheet (SDS) chemical hazard information can vary substantially between suppliers. End users should not rely solely on hazard information contained in the SDS when using the chemical at elevated temperatures or pressures, or with other chemicals with which the chemical could react. Additional hazard analyses may be needed to prevent process safety incidents.

Companies should seek additional publicly available information, or obtain additional information through testing, to supplement information contained in a material's SDS.

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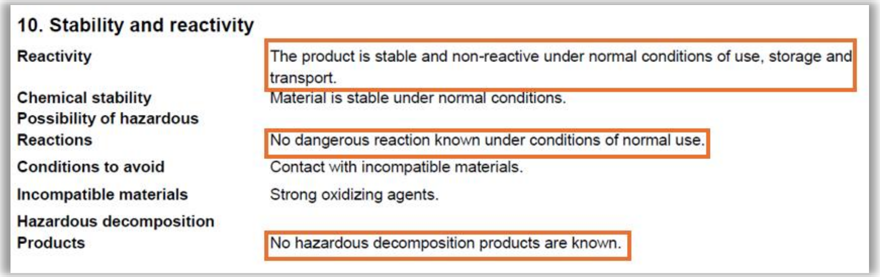
[a] 29 C.F.R. § 1910.1200 *Hazard Communication*

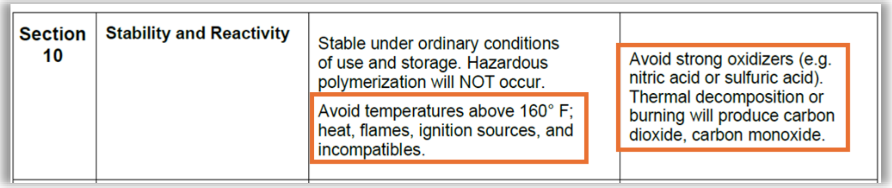


10. Stability and reactivity

Reactivity	The product is stable and non-reactive under normal conditions of use, storage and transport.
Chemical stability	Material is stable under normal conditions.
Possibility of hazardous Reactions	No dangerous reaction known under conditions of normal use.
Conditions to avoid	Contact with incompatible materials.
Incompatible materials	Strong oxidizing agents.
Hazardous decomposition Products	No hazardous decomposition products are known.

Figure 32. Section 10 of the SDS provided to Givaudan by its invert sugar manufacturer. (Credit: Givaudan, annotated by CSB)

The CSB obtained an SDS for a similar invert sugar material from a different manufacturer and found that it warned that the material could undergo a hazardous decomposition reaction (**Figure 33**). Although this manufacturer was aware of the hazards associated with this decomposition reaction, this information does not appear to be a broadly published or widely known reaction mechanism.[a]



Section 10	**Stability and Reactivity**	Stable under ordinary conditions of use and storage. Hazardous polymerization will NOT occur. Avoid temperatures above 160° F; heat, flames, ignition sources, and incompatibles.	Avoid strong oxidizers (e.g. nitric acid or sulfuric acid). Thermal decomposition or burning will produce carbon dioxide, carbon monoxide.

Figure 33. Section 10 of an SDS the CSB found for an invert sugar manufactured by a different supplier. (Credit: United Sugar Producers and Refiners, annotated by CSB)

This inconsistency in the invert sugar SDS information aligns both with the Center for Chemical Process Safety's (CCPS)[b] observation that SDS chemical hazard information can vary substantially between suppliers [16, p. 74] and with an EPA Safety Alert issued in 1999, which warned "[SDS] chemical hazard information can vary substantially depending on the provider [17, p. 2]." The CSB previously identified similar discrepancies in safety information presented in SDSs in its 2023 Optima Belle investigation report [18]. The inclusion of the decomposition temperature in the invert sugar SDS could have helped D.D. Williamson and Givaudan realize the potential for a hazardous decomposition reaction during the caramel coloring manufacturing process. Testing performed by the CSB indicates that the decomposition of the invert sugar used at the Louisville facility begins when the temperature exceeds 267°F, which is within the typical operating temperature range for Product 484.

The CSB concludes that safety information communicated in sugar ingredient safety data sheets (SDSs) can vary significantly among suppliers. The SDS provided to Givaudan by the invert sugar manufacturer did not warn of the hazardous decomposition reaction potential of the invert sugar ingredient, while an SDS by a different manufacturer did warn of the decomposition hazard. Improved hazard information in sugar ingredient SDSs can help prevent future catastrophic sugar decomposition incidents.

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[a] The CSB found that there are a limited number of published technical references that specifically address the decomposition of sugar when heated at high temperatures.

[b] The CCPS is an industry group that publishes guidelines for implementing practices to improve process safety.

The CSB issues the following recommendations:

- To International Molasses Corporation Ltd. (Givaudan's invert sugar supplier): Update all invert sugar safety data sheets to include: the decomposition temperature, the consequences of exceeding that temperature, and the decomposition products produced (for example, carbon dioxide). (*2024-06-I-KY-R11*)

- To the Corn Refiners Association (trade association of corn refiners whose products include glucose syrups and high fructose corn syrup [19]): Alert association members who manufacture corn syrup of the November 12, 2024, Givaudan incident and its causes, including but not limited to the sugar ingredient decomposition reaction that led to Reactor 6's rupture. Request that they update their corn syrup safety data sheets to include: the decomposition temperature, the consequences of exceeding that temperature, and the decomposition products produced (for example, carbon dioxide). (*2024-06-I-KY-R12*)

4.2 COMMITMENT TO MANAGING PROCESS SAFETY

As described in this section, the CSB found that the Louisville facility was seriously deficient in its management of process safety throughout much of its operating history. After the EPA RMP rule was published in 1996, the Louisville facility failed to conduct the required hazard reviews of its process—an important element of managing process safety—by the rule's 1999 due date.[a] A lack of hazard reviews contributed to the 2003 incident that destroyed a portion of the facility and fatally injured one worker. Following the 2003 incident, the involvement of both the CSB and EPA spurred the Louisville facility to improve its written policies to better manage its process safety. However, the facility largely failed to implement those new process safety policies after the CSB investigation and EPA oversight ended.

The Louisville facility's deficient management of the process safety of its manufacturing processes contributed to key personnel involved in the design of Reactor 6 being unaware of important information, including the 2012 Product 034 reactivity testing results and the resulting increases in emergency pressure relief system sizing for Reactors 3 and 4. Had they been aware of this important safety information, they might have equipped Reactor 6 with a relief system designed for the sugar ingredient decomposition scenario, which could have prevented the 2024 vessel rupture.

4.2.1 BACKGROUND

Following the 2003 incident, the CSB found in its investigation that D.D. Williamson did not conduct engineering reviews to understand the potential hazards of its process or select safeguards to protect from those hazards. EPA similarly identified a hazard review gap after conducting an RMP program audit following the 2003 incident (**Figure 34**). As a result of this identified safety deficiency, the CSB recommended that D.D. Williamson "implement a hazard evaluation procedure to determine the potential for catastrophic incidents and necessary safeguards" [7]. EPA subsequently initiated RMP enforcement actions against the company after the incident and, in a 2009 Consent Decree, required D.D. Williamson to hire an independent third-party

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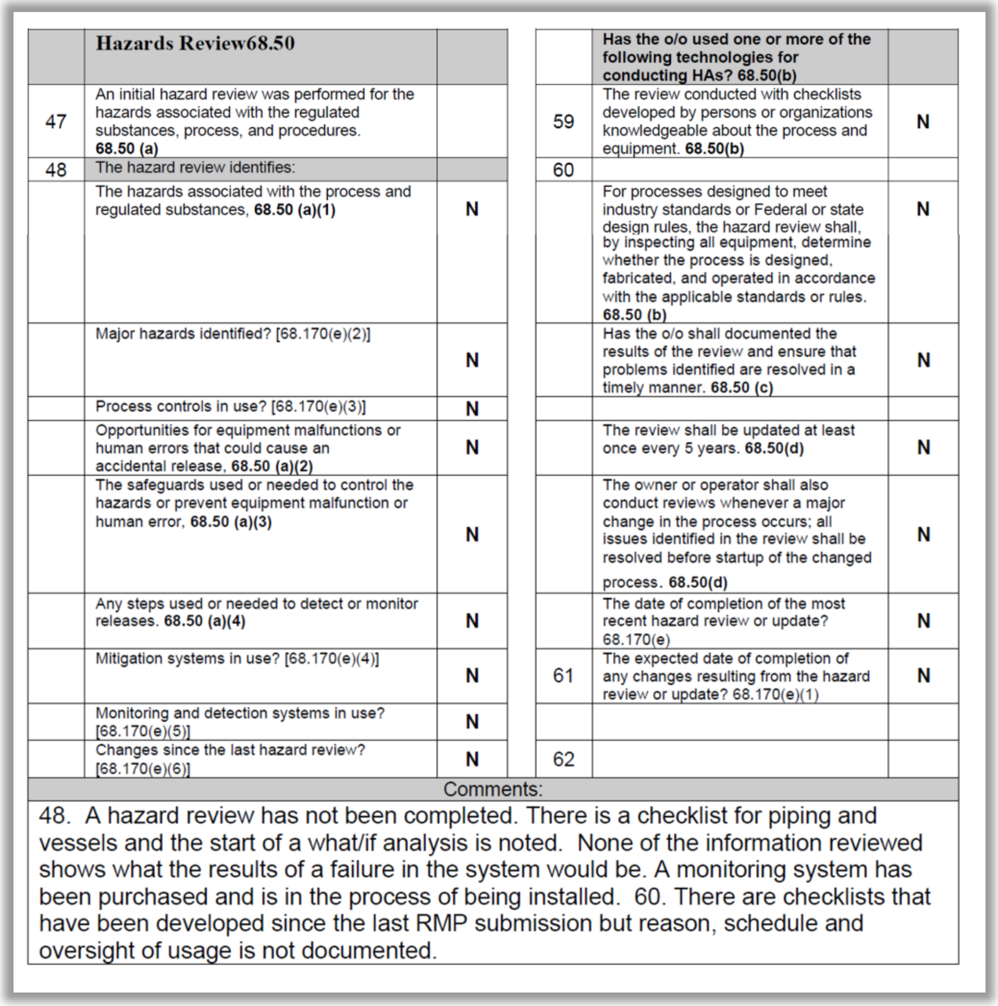
[a] 40 C.F.R. § 68.10 *Chemical Accident Prevention Provisions - Applicability*

engineering consultant to evaluate and recommend improvements to other various facets of the facility's safety management system and to implement those recommendations.



	Hazards Review68.50			**Has the o/o used one or more of the following technologies for conducting HAs? 68.50(b)**	
47	An initial hazard review was performed for the hazards associated with the regulated substances, process, and procedures. **68.50 (a)**		59	The review conducted with checklists developed by persons or organizations knowledgeable about the process and equipment. **68.50(b)**	**N**
48	The hazard review identifies:		60		
	The hazards associated with the process and regulated substances, **68.50 (a)(1)**	**N**		For processes designed to meet industry standards or Federal or state design rules, the hazard review shall, by inspecting all equipment, determine whether the process is designed, fabricated, and operated in accordance with the applicable standards or rules. **68.50 (b)**	**N**
	Major hazards identified? [68.170(e)(2)]	**N**		Has the o/o shall documented the results of the review and ensure that problems identified are resolved in a timely manner. **68.50 (c)**	**N**
	Process controls in use? [68.170(e)(3)]	**N**			
	Opportunities for equipment malfunctions or human errors that could cause an accidental release, **68.50 (a)(2)**	**N**		The review shall be updated at least once every 5 years. **68.50(d)**	**N**
	The safeguards used or needed to control the hazards or prevent equipment malfunction or human error, **68.50 (a)(3)**	**N**		The owner or operator shall also conduct reviews whenever a major change in the process occurs; all issues identified in the review shall be resolved before startup of the changed process. **68.50(d)**	**N**
	Any steps used or needed to detect or monitor releases. **68.50 (a)(4)**	**N**		The date of completion of the most recent hazard review or update? 68.170(e)	**N**
	Mitigation systems in use? [68.170(e)(4)]	**N**	61	The expected date of completion of any changes resulting from the hazard review or update? 68.170(e)(1)	**N**
	Monitoring and detection systems in use? [68.170(e)(5)]	**N**			
	Changes since the last hazard review? [68.170(e)(6)]	**N**	62		

Comments:

48. A hazard review has not been completed. There is a checklist for piping and vessels and the start of a what/if analysis is noted. None of the information reviewed shows what the results of a failure in the system would be. A monitoring system has been purchased and is in the process of being installed. 60. There are checklists that have been developed since the last RMP submission but reason, schedule and oversight of usage is not documented.

Figure 34. Excerpt from 2004 RMP audit conducted by EPA after the 2003 incident. o/o stands for "owner/operator." (Credit: EPA)

As a result of the CSB recommendation, in 2008, D.D. Williamson hired an engineering consulting company to lead a HAZOP of the liquid caramel coloring production facility. As described in *Section 1.8.2* of this report, this HAZOP issued the recommendation that led to the 2012 reactivity testing of Product 034. D.D. Williamson also established a Management of Change policy, which required the facility to "ensure that appropriate design reviews of proposed changes are completed prior to any changes made in the plant."

As a result of the 2009 EPA RMP enforcement requirements, D.D. Williamson again hired an independent third-party consultant to review its internal safety management documents and make recommendations for improvement. After that review, D.D. Williamson made additional documentation improvements that could improve the facility's management of process safety, including establishing a new Management of Change request form and developing various new policies and procedures to safely operate the facility, including an Environmental Health and Safety Management System Manual that required "D.D. Williamson [to] identify and evaluate their hazards and risks each year (or earlier if there is a change in circumstances)" as part of its Hazard Identification and Risk Assessment program.

In 2009, the CSB closed its recommendations as complete (i.e., "Closed - Acceptable Action"), and in 2015, EPA closed its enforcement actions. Despite the improved written policies that were created during EPA oversight and after the CSB investigation that should have improved the facility's management of process safety, D.D. Williamson did not commit to implementing the new policies after government involvement ended, as will be described in *Section 4.2.2* below. Additionally, in 2007 the Louisville facility had reduced its aqueous ammonia storage below EPA's defined threshold quantity and, as a result, the facility was no longer subject to the EPA RMP regulation's safety management requirements. As previously noted, however, the Louisville facility was still subject to OSHA's and EPA's General Duty Clauses, which require that facilities be designed and maintained to protect workers and the environment.

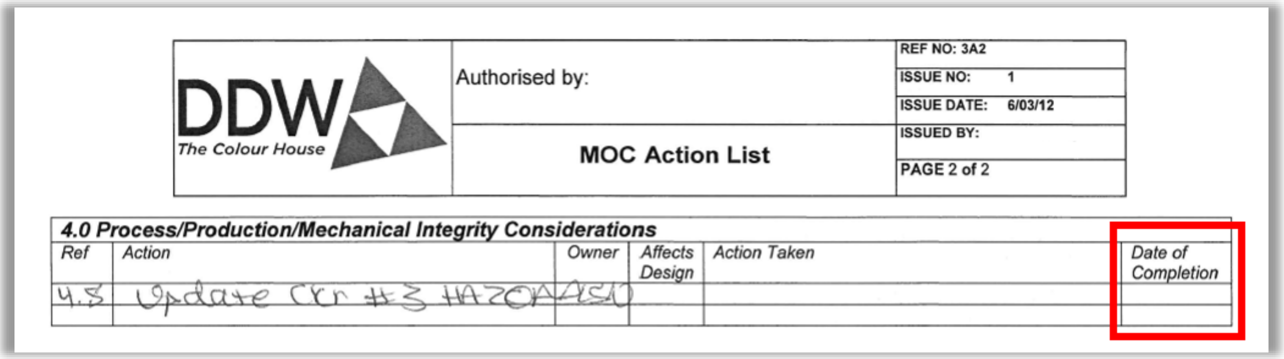
4.2.2 LOUISVILLE FACILITY'S PROCESS SAFETY POLICY IMPLEMENTATION DEFICIENCIES

The CSB identified the deficiencies below related to the Louisville facility's process safety policy implementation that contributed to the 2024 incident.

Deficiency #1: *Inadequate Management of Change policy implementation contributed to the Reactor 6 design team being unaware of both the 2012 reactivity testing and the resulting safety improvements to the Reactor 3 and Reactor 4 relief systems, which contributed to the installation of an undersized emergency pressure relief system for Reactor 6.*

In 2006, D.D. Williamson established a Management of Change (MOC) policy, which required the facility to "ensure that appropriate design reviews of proposed changes are completed prior to any changes made in the plant." MOC documents are important records of plant equipment changes that should be reviewed in hazard analyses when evaluating plant hazards and determining needed safeguards. In addition, both MOC and hazard analysis documents are useful sources of information for new personnel when they are working to gain an understanding of process plant operating history and reasoning for current equipment designs.

In 2012, D.D. Williamson conducted an MOC analysis for the size increase of the Reactor 3 relief system following the reactivity testing, but the company did not follow through with critical action items. In the Reactor 3 Management of Change, D.D. Williamson created an action item to update the HAZOP with the relief system changes but then did not implement the action, as shown in **Figure 35**. As a result, documentation of the Reactor 3 relief system changes and the reasoning for those changes were limited. Additionally, D.D. Williamson failed to follow its MOC policy by not completing an MOC analysis for the changes to the relief system on Reactor 4.



DDW The Colour House

Authorised by:		REF NO: 3A2
		ISSUE NO: 1
		ISSUE DATE: 6/03/12
	MOC Action List	ISSUED BY:
		PAGE 2 of 2

4.0 Process/Production/Mechanical Integrity Considerations

Ref	Action	Owner	Affects Design	Action Taken	Date of Completion
4.5	Update Rcr #3 HAZOP	ASD			

Figure 35. Action List for the Reactor 3 “PRV Size Change” Management of Change. For the action to “update [Reactor] #3 HAZOP,” both the “Action Taken” and “Date of Completion” boxes are empty. (Credit: Givaudan, annotated by CSB)

Following the 2024 incident, CSB investigators learned that the Reactor 6 design team was unaware of the size differences in the relief systems among Reactors 1–4, as the Louisville facility did not have clear documentation detailing the design differences or the rationale for them. The absence of sufficient MOC documentation and the lack of a HAZOP document detailing the hazards and safeguards within the facility likely contributed to the Reactor 6 design team being unaware of these important relief system sizing differences.

The CSB concludes that after increasing the emergency pressure relief system sizes for Reactors 3 and 4 to safeguard against the pressures produced from the reaction identified in the 2012 reactivity testing of Product 034, D.D. Williamson did not clearly document this important safety improvement as a safeguard due to inadequacies in implementing the facility’s MOC program. As a result, the Louisville facility had minimal written records to help future personnel understand the purpose and rationale for these relief system design changes. The lack of written records contributed to the Reactor 6 design team being unaware of both the 2012 Product 034 reactivity testing results and the differences in relief system sizes among the existing reactors and, in turn, ultimately contributed to the installation of an undersized relief system for Reactor 6.

Deficiency #2: *No hazard analyses for Reactors 1–4 were conducted after 2008, resulting in a loss of institutional knowledge regarding the 2012 reactivity testing and subsequent sizing increases to the emergency pressure relief systems of Reactor 3 and Reactor 4. These knowledge gaps contributed to the installation of an undersized emergency pressure relief system for Reactor 6.*

Following the 2008 HAZOP for Reactors 1–4, D.D. Williamson never again completed another hazard analysis for the reactors. D.D. Williamson did not conduct hazard reviews "at least once every five years" as required by the EPA RMP rule,[a] as the Louisville facility had reduced its aqueous ammonia storage below EPA's defined threshold quantity in 2007 and, as a result, was no longer subject to the EPA RMP regulation's safety management requirements. The facility also did not follow its own internal requirement to evaluate hazards and risks each year, as specified by its Environmental Health and Safety Manual. Analyzing process hazards and selecting safeguards to protect against those hazards are critical ways for a facility to fulfill its general duty[b] to design and maintain a safe facility to protect its workers, the environment, and the community.

Because additional hazard analyses were not completed, the Louisville facility never again formally evaluated the reactivity hazards of Product 034 and, importantly, (1) never documented the newly discovered Product 034 reactivity information as a hazard in the site's hazard analysis documentation, and (2) never formally documented the increased emergency pressure relief system size as a safeguard against that reactivity hazard.[c] As a result, the Reactor 6 design team, whose work was conducted after the Product 034 reactivity information was collected and the relief systems for Reactors 3 and 4 were increased in size, did not understand this important history. This information gap prevented reactive hazards from being considered when sizing the emergency pressure relief system for Reactor 6.

KEY LESSON

Hazard analyses and effective change management processes are critical aspects of a robust process safety management system. Additionally, they are essential tools to document institutional knowledge of identified hazards and their safeguards, allowing this important information to be communicated to new personnel who were not at the site when the hazards were discovered and the safeguards were established.

The CSB concludes that after 2008, the Louisville facility never again completed another hazard analysis for its caramel coloring reactors. Had Louisville facility personnel continued to conduct hazard analyses, they should have updated the associated documentation to include the reactivity information discovered in 2012 regarding Product 034 and the related emergency pressure relief system size increases as safeguards. This documentation should have informed the Reactor 6 design team of the 2012 chemical reactivity testing results of Product 034 and the subsequent pressure relief design changes to Reactors 3 and 4, which could have helped the team to recognize that Reactor 6 needed a larger emergency pressure relief system.

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[a] 40 C.F.R. § 68.50(d)

[b] 42 U.S. Code § 7412 (r)(1) and 29 U.S. Code § 654 (a)(1)

[c] The ASME Boiler and Pressure Vessel Code requires facilities to "determin[e] all potential overpressure scenarios and the method of overpressure protection used to mitigate each scenario." The Commonwealth of Kentucky adopted ASME Boiler and Pressure Vessel Code requirements as law for both boilers and pressure vessels beginning in 1980. The Louisville facility had no record of relief system design bases that justified the relief system design and sizing selected for Reactors 1, 2, 5, and 6.

The CSB also concludes that the Louisville facility failed to follow key elements of its own safety management program, including management of change and hazard analyses. Had the Louisville facility fully implemented its written safety management system, it would have provided opportunities for facility personnel to be aware that there were reactive hazards present at the site. This, in turn, could have led to the realization that additional reactivity analyses and emergency pressure relief design evaluations were warranted, which could have prevented the incident.

Deficiency #3: *No hazard analysis was conducted for the design of Reactors 5 and 6, which would have been a key opportunity to ensure the emergency pressure relief systems for the reactors were appropriately sized.*

During the design and before the installation of Reactors 5 and 6, the Louisville facility did not conduct hazard analyses for the reactors, which could have documented known hazards and safeguards to protect against them. While the site did conduct an MOC analysis for the addition of Reactors 5 and 6, which identified the need to complete a Process Hazard Analysis (PHA), the facility ultimately concluded that a PHA was not necessary because the Reactor 5 and 6 design was a copy of the already-existing Reactor 2.

KEY LESSON

Companies should ensure they are following industry guidance for revalidation timelines of hazard analyses and have competent personnel leading and contributing to the discussions. If companies do not have adequate personnel, outside experts should be hired to assist in identifying hazards and safeguards.

The CSB concludes that the Louisville facility did not perform a PHA on the designs of Reactors 5 and 6 before their installation and operation. Conducting a hazard analysis on the Reactor 5 and 6 designs would have been a key opportunity for the Louisville facility to review previous hazard analyses, past facility change management documents, chemical reactivity testing results, and the planned safeguard designs for Reactor 5 and 6 to ensure all identified hazards were prevented or controlled. Since a PHA was not completed, a key opportunity was missed to identify that Reactor 6's emergency pressure relief system needed to be designed to relieve the gases/pressure generated from the chemical reaction of caramel coloring ingredients.

The CSB recommends that Givaudan contract a third party to conduct a hazard analysis of each caramel coloring facility. Require this analysis to address reactivity hazards and include a review of the reactivity data obtained from implementing CSB Recommendation 2024-06-I-KY-R1. Implement the recommendations issued by the third party as a result of the hazard analysis. (*2024-06-I-KY-R2*)

4.2.3 LACK OF PROCESS SAFETY POLICY "OWNER"

Because the Louisville facility experienced personnel changes over the years due to turnover, no personnel involved in the 2021 Reactor 5 and 6 designs had personal knowledge or experience with the 2012 reactivity testing of Product 034 or the resulting 2013 emergency pressure relief system sizing changes to Reactors 3 and 4. As a result, strong documentation (for example, change management and hazard analysis documentation) was essential to maintain this institutional knowledge. The facility's poor implementation of its process safety policies, however, prevented that documentation from being produced (*Section 4.2.2*).

The Center for Chemical Process Safety (CCPS) is an industry group that publishes guidelines for implementing practices that improve process safety. The CCPS publication *Guidelines for Risk Based Process Safety* outlines a "management system structure, offers examples of emerging effective practices, and defines a risk-based strategic implementation process that can help companies find effective ways to break through their process safety management barriers to become more effective and to operate safer processes" [20, p. 8]. The CCPS's *Guidelines for Risk Based Process Safety* are a broadly accepted framework for process safety management[a] consisting of 20 elements to help organizations design and implement more effective process safety management systems. The *Guidelines* are intended as a framework that companies of any size and risk profile can adapt to their operations.

One of the pillars of CCPS's *Risk Based Process Safety* framework is "Commit to Process Safety." One of the elements essential to this core pillar is "Compliance with Standards"—including compliance with internal standards, external standards, regulatory requirements, and laws [20, p. 68]. The CCPS framework provides guidance on maintaining a dependable practice for the "Compliance with Standards" element, including a recommendation to "[e]nsure consistent implementation of the standards system." The framework recommends that to achieve this goal, facilities should:

1. Develop a written program that identifies all process safety obligations;
2. **Establish a standards element owner** (emphasis added); and
3. Define the roles and responsibilities for personnel assigned to perform activities to help ensure compliance with applicable process safety-related standards [20, p. 75].

Under both D.D. Williamson's and Givaudan's ownership, the Louisville facility did not sufficiently assign or train an employee to have oversight responsibility and be accountable for the implementation of (i.e., "to own") the process safety policies. While the facility's Environmental Health and Safety Management System Manual required Hazard Identification and Risk Assessments to be conducted each year, there was no one assigned to oversee that element, and no detailed procedure was developed for conducting the assessments. For a safety management system to be successful, it must be overseen by competent person(s) who have the authority and knowledge to carry out the assigned duties.

The CSB concludes that the lack of an "owner" of the Louisville facility's process safety policies contributed to the Louisville facility inconsistently conducting MOC reviews, action item implementation, and process hazard evaluations as part of the site's Hazard Identification and Risk Assessment program. The lack of strong company leadership on the implementation of these process safety policies directly contributed to personnel involved in the Reactor 5 and Reactor 6 design being unaware of the 2012 chemical reactivity testing results of Product 034 and the resulting Reactor 3 and 4 emergency pressure relief system sizing increases, and ultimately led to the installation of an undersized emergency pressure relief system for Reactor 6. For a safety management system to be successful, it must be overseen by competent person(s) who have the authority and knowledge to carry out the assigned duties. Implementing a robust process safety management system, such as through the

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[a] This report distinguishes the terms "process safety management" (lowercase) as the practices used to improve process safety and "Process Safety Management (PSM)" to refer to OSHA's PSM standard.

framework detailed in the CCPS's *Guidelines for Risk Based Process Safety,* can help Givaudan improve the process safety management of its caramel coloring facilities and prevent future process safety incidents.

To improve process safety leadership and process safety management at Givaudan's caramel coloring facilities, **the CSB recommends** that Givaudan:

- Contract a third party to develop a process safety management system to be used at each Givaudan caramel coloring facility. This third party shall:
    a. Ensure the process safety management system is in alignment with current industry guidance such as the CCPS's *Guidelines for Risk Based Process Safety*.
    b. Ensure that the process safety management system requires hazard reviews/analyses to be conducted at prescribed intervals and include:
        (1) the review/incorporation of reactivity data from CSB Recommendation 2024-06-I-KY-R1 and any additional reactivity data obtained during the course of operating any caramel coloring facility,
        (2) the review/analysis of any process changes that could affect relief system designs, and
        (3) the review/updating of the facility siting study from CSB Recommendation 2024-06-I-KY-R7, as appropriate. (*2024-06-I-KY-R3*)
- At each caramel coloring facility, hire a new or identify a current employee who is competent in process safety management concepts. Establish this employee's job duties to specifically include overseeing the caramel coloring facility's process safety management system established in 2024-06-I-KY-R3, its implementation, and personnel training on the system's elements. (*2024-06-I-KY-R4*)
- Create and fill a corporate senior leadership position responsible for overseeing process safety at all Givaudan caramel coloring facilities, or identify a current senior leader who is competent in process safety management concepts to fill this role. Establish this senior leader's job duties to oversee the process safety management system implementation at all Givaudan caramel coloring facilities. Assign this individual to develop corporate-level process safety management system policies to ensure consistent development and implementation of process safety management systems at all Givaudan caramel coloring facilities. (*2024-06-I-KY-R8*)
- For each caramel coloring facility, contract a third party to design adequate emergency pressure relief systems for the vessels involved in caramel coloring manufacturing. Ensure the third party reviews/incorporates all reactivity data obtained from the testing required by CSB Recommendation 2024-06-I-KY-R1 when designing the emergency pressure relief systems. Document and maintain each vessel's relief system design basis for the service life of the vessel. (*2024-06-I-KY-R5*)

4.2.4 NEED FOR INDUSTRY GUIDANCE

In several of the CCPS's publications, including *Guidelines for Risk Based Process Safety, Essential Practices for Managing Chemical Reactivity Hazards,* and *Guidelines for Implementing Process Safety Management*, the

CCPS provides a process safety management system framework for identifying and controlling process hazards. For facilities like the Givaudan Louisville facility that do not process chemicals in quantities greater than the defined threshold quantities in the OSHA PSM standard and EPA RMP regulation, the CCPS guidance can assist these facilities in achieving their general duty to design and maintain safe facilities to protect workers and the environment.

As described in *Section 4.1.2*, there is no industry guidance specifically for the safe manufacturing of caramel coloring products. The development of industry guidance on safely manufacturing caramel coloring products, that, at a minimum, details the reactive hazards of caramel coloring sugar ingredients and recommends manufacturers to establish effective safety management systems based on the above CCPS guidance, can help caramel coloring manufacturers like Givaudan prevent future catastrophic vessel overpressure incidents.

The CSB recommends that the ITCA publish a technical safety bulletin for caramel coloring manufacturing that encourages caramel color manufacturers to ensure known hazards, including sugar ingredient decomposition, are addressed. Emphasize the importance of obtaining information on calorimetric properties of sugar ingredients and ensuring appropriately sized emergency pressure relief systems to safely vent pressure and gases that could be produced by sugar ingredient decomposition reactions, as well as other overpressure scenarios identified in hazard analyses. Refer caramel color manufacturers to the CSB's investigation report for additional details. Recommend in the technical safety bulletin that caramel coloring manufacturers implement, as appropriate, process safety management systems that are in alignment with local requirements and chemical industry good practice guidance, such as the Center for Chemical Process Safety *Guidelines for Risk Based Process Safety, Essential Practices for Managing Chemical Reactivity Hazards*, and *Guidelines for Implementing Process Safety Management*.

KEY LESSON

Companies should set, define, and train all employees on safe operating limits to ensure personnel are able to identify that the equipment has reached an unsafe condition, troubleshooting efforts need to end, and predetermined actions must be taken to protect employees.

Visual and audible alarms should be utilized to alert personnel that the safe limits were exceeded, and the established response steps should be initiated.

4.3 SAFE OPERATING LIMITS

As described in this section, the Louisville facility did not provide adequate guidance for workers to fully understand and properly respond to the dangerously high pressure and temperature inside Reactor 6 on the day of the incident. As a result, personnel continued to troubleshoot the high pressure and temperature even after Reactor 6 had exceeded its safe operating limits, and personnel remained inside the facility near Reactor 6 until it catastrophically ruptured.

4.3.1 BACKGROUND

Troubleshooting is an activity that operators undertake to restore process conditions to a safe state. In *Process Risk and Reliability Management*, process safety author Ian Sutton argues that:

> One of the most important decisions that an operator has to make when an abnormal operation occurs is to determine whether or not the situation with which he is faced represents "trouble" or an "emergency." This decision often has to be made quickly and under considerable pressure. For this reason, knowledge of safe limits for all critical parameters is vital [21, p. 522].

The CCPS defines a "safe operating limit" as:

> a value for a critical operating parameter that defines the equipment […] safe operating envelope beyond which a process will not intentionally be operated due to the risk of imminent catastrophic equipment failure or loss of containment.
>
> Operational or mechanical corrective action ceases and immediate predetermined actions are taken at these critical operating parameter values in order to bring equipment and process units to a safe state [22, p. 135]. (emphasis added)

Alarms can be essential for alerting workers when a safe operating limit is reached. The CCPS book Guidelines for Engineering Design for Process Safety states that typical alarms can include those intended for (among other alarm intents):

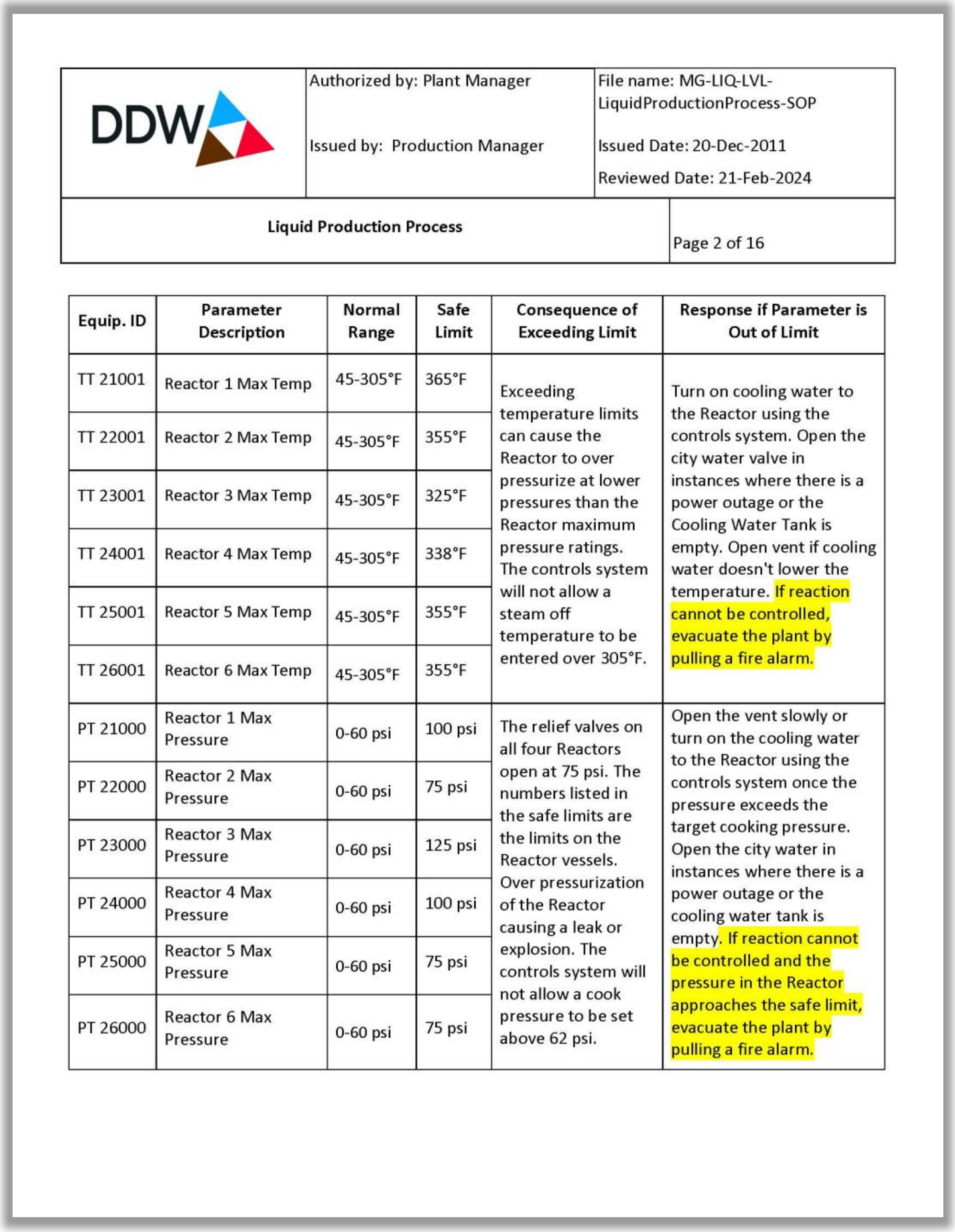
- "***Equipment Malfunction*** – Malfunction of equipment can lead to plant upset which the plant control scheme may not be able to correct. For example, a pressure control valve in an overhead vapor line which gets suck in the closed position may cause the pressure in the system to rise and result in the lifting of a relief valve."
- "***Equipment Protection*** – The malfunction of a system which can lead to damage to the associated (or downstream) equipment. For example, high temperatures on a product rundown line that may exceed a tank design limit" [22, p. 133].

The CCPS guidance also states, "Proper alarm design will follow a rationalization and prioritization process to determine the need for the alarm, the require[d] response for the alarm, and the priority of the response. Operators should be trained to understand the importance of the safe operating limit alarms" [22, p. 133]. (emphasis added)

4.3.2 SAFE OPERATING LIMITS AT THE LOUISVILLE FACILITY

After the 2003 vessel rupture incident at the Louisville facility, EPA's 2009 enforcement actions required D.D. Williamson to hire an independent third-party engineering consultant to, among other things, evaluate and recommend improvements to the Louisville facility's safe operating limits. After the consultant issued recommendations to the Louisville facility, in 2011 the Louisville facility established safe operating limits for each of its reactors and included them in the standard operating procedures. These limits were later updated to include safe operating limits for the new Reactors 5 and 6.

The safe operating limits established for each reactor are shown in **Figure 36**. For each reactor, the established temperature safe operating limit was the vessel's MAWT, and the established pressure safe operating limit was the vessel's MAWP. The facility's document establishing the safe operating limits states that "[i]f reaction cannot be controlled and the pressure in the [reactor] approaches the safe limit, evacuate the plant by pulling a fire alarm."



DDW	Authorized by: Plant Manager Issued by: Production Manager	File name: MG-LIQ-LVL-LiquidProductionProcess-SOP Issued Date: 20-Dec-2011 Reviewed Date: 21-Feb-2024
Liquid Production Process		Page 2 of 16

Equip. ID	Parameter Description	Normal Range	Safe Limit	Consequence of Exceeding Limit	Response if Parameter is Out of Limit
TT 21001	Reactor 1 Max Temp	45-305°F	365°F	Exceeding temperature limits can cause the Reactor to over pressurize at lower pressures than the Reactor maximum pressure ratings. The controls system will not allow a steam off temperature to be entered over 305°F.	Turn on cooling water to the Reactor using the controls system. Open the city water valve in instances where there is a power outage or the Cooling Water Tank is empty. Open vent if cooling water doesn't lower the temperature. If reaction cannot be controlled, evacuate the plant by pulling a fire alarm.
TT 22001	Reactor 2 Max Temp	45-305°F	355°F		
TT 23001	Reactor 3 Max Temp	45-305°F	325°F		
TT 24001	Reactor 4 Max Temp	45-305°F	338°F		
TT 25001	Reactor 5 Max Temp	45-305°F	355°F		
TT 26001	Reactor 6 Max Temp	45-305°F	355°F		
PT 21000	Reactor 1 Max Pressure	0-60 psi	100 psi	The relief valves on all four Reactors open at 75 psi. The numbers listed in the safe limits are the limits on the Reactor vessels. Over pressurization of the Reactor causing a leak or explosion. The controls system will not allow a cook pressure to be set above 62 psi.	Open the vent slowly or turn on the cooling water to the Reactor using the controls system once the pressure exceeds the target cooking pressure. Open the city water in instances where there is a power outage or the cooling water tank is empty. If reaction cannot be controlled and the pressure in the Reactor approaches the safe limit, evacuate the plant by pulling a fire alarm.
PT 22000	Reactor 2 Max Pressure	0-60 psi	75 psi		
PT 23000	Reactor 3 Max Pressure	0-60 psi	125 psi		
PT 24000	Reactor 4 Max Pressure	0-60 psi	100 psi		
PT 25000	Reactor 5 Max Pressure	0-60 psi	75 psi		
PT 26000	Reactor 6 Max Pressure	0-60 psi	75 psi		

Figure 36. Reactors 1–6 safe operating limits (Credit: Givaudan, annotated by CSB)

4.3.3 OPERATOR ACTIONS ON THE DAY OF THE INCIDENT

On the day of the incident, when the Reactor 6 temperature and pressure began to rise above their control system set points, operators performed the prescribed troubleshooting steps by activating the cooling water system and ensuring that the cooling water tank was full. Personnel also conducted troubleshooting efforts to verify the position of the vent valve (see *Section 2*). After the pressure reached the safe operating limit of 75 psig at 2:54 p.m., however, personnel continued their troubleshooting efforts. Moreover, when the temperature reached the safe operating limit of 355°F at 2:56 p.m., troubleshooting still continued. No alarms or other indications automatically activated to alert operators that these not-to-exceed limits had been reached, as the Louisville facility had not established alarms for these limits, and no one pulled a fire alarm to evacuate the facility, despite this being the prescribed action to take when a safe operating limit was reached.

The CSB concludes that had employees pulled the fire alarm to evacuate the facility at 2:54:04 p.m.—when the pressure safe operating limit was reached—personnel would have had about 3.5 minutes to evacuate the building before the Reactor 6 explosion occurred at 2:57:41 p.m.

4.3.4 SAFE OPERATING LIMIT TRAINING

Givaudan provided the CSB with “Proficiency Certification” documents for its operators, which detailed the multiple operation procedures reviewed and included for each procedure title (1) the operator trainee’s signed affirmation that they “reviewed [the procedure],” (2) the trainer’s signed affirmation that they “demonstrated tasks,” and (3) a certifying manager’s signature. This documentation indicates that D.D. Williamson, and subsequently Givaudan, provided initial “on-the-job” training to new operators on various procedures, including the operating procedure that specified the equipment safe operating limits. Givaudan, however, did not provide the CSB with details of the training or specify whether safe operating limits were specifically reviewed. Additionally, no records were provided detailing whether operators received any refresher training after their initial training. The CSB found that key operations employees at the facility on the day of the incident were not aware of the specific Reactor 6 safe operating limits or the required response when the limits were exceeded.

4.3.5 CONCLUSION

The CSB concludes that:

- While the Louisville facility had established pressure and temperature safe operating limits for its reactors, the Louisville facility operators were not familiar with the safe operating limit values due to inadequate training. As a result, operators and maintenance personnel continued troubleshooting the Reactor 6 abnormal operation on the day of the incident and did not take the prescribed action of evacuating the building when the safe operating limits were exceeded.

- The Louisville facility did not adequately train its operators on the values of, purpose of, or required response to the established safe operating limits. The Louisville facility also did not establish other indicators, such as alarms or other control room notifications, to alert operators that a safe operating limit had been exceeded.

- Givaudan's safe operating limits program was not effective.

The CSB recommends that Givaudan establish a corporate policy that will address training operations personnel on defined safe operating limits and actions to take if those limits are exceeded. (*2024-06-I-KY-R8)*

The CSB recommends that for each caramel coloring facility, Givaudan establish automatic alerts, such as alarms or control screen indications, to notify operators when a safe operating limit has been reached. Follow industry guidance, such as the guidance presented in the Center for Chemical Process Safety book *Guidelines for Engineering Design for Process Safety (2nd Edition)*, Chapter 5 *General Design*. Provide initial and refresher training for operations personnel on the established safe operating limits including the actions to take if these limits are exceeded. (*2024-06-I-KY-R6)*

KEY LESSON

When buildings are occupied by personnel or contain equipment critical for safe operations, they must be adequately designed or located to protect from fires, explosions, or toxic releases. Companies should conduct facility siting analyses of normally occupied spaces, such as control rooms, and make design changes as appropriate, to protect people and critical equipment from identified process hazards.

4.4 FACILITY SITING

Two employees were fatally injured at the Louisville facility when the blast wave created by the bursting Reactor 6 damaged the control room where they were working, causing the control room to collapse on top of them. The control room was located just 40 feet from Reactor 6 and was not constructed to be blast-resistant.[a] As described in this section, conducting "facility siting" analyses to identify fire, explosion, or toxic release hazards and their potential effects on human-occupied structures, and then adequately designing or locating those structures to reduce risk from those hazards to personnel, can help prevent future similar events at Givaudan facilities.

4.4.1 PROGRESSION OF CONTROL ROOM SAFETY IN THE PROCESS INDUSTRY

In the late 20th century, multiple process accidents occurred causing severe damage to occupied control rooms and resulting in employee fatalities. Some of these incidents include:

1. **Flixborough (Nypro UK) Explosion (1974)**. Cyclohexane released from a process facility, forming a large flammable vapor cloud. The vapor cloud found an ignition source, causing an explosion. Twenty-eight workers were killed. Eighteen fatalities occurred in the control room as a result of the windows shattering and the collapse of the roof. No one escaped from the control room [23].
2. **Phillips 66 Houston Chemical Complex Explosion and Fire (1989)**. A vapor cloud was released from process equipment at the Phillips 66 facility in Pasadena, Texas. The vapor cloud contained approximately 85,000 pounds of a mixture of ethylene, isobutane, hexene, and hydrogen. The cloud

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[a] As defined by the CCPS, blast-resistant buildings are "[b]uildings that are structurally designed to withstand an explosion generated load (pressure and impulse) while sustaining a predetermined amount of damage" [44].

found an ignition source, exploded, and set off a chain of subsequent explosions that ultimately killed 23 people, some of whom were located within buildings at the time of the explosion. In its 1990 report on the incident, OSHA concluded that "buildings containing personnel […] were not separated from process units in accordance with accepted engineering principles or designed with sufficient resistance to fire and explosion" [24].

3. **Hickson & Welch incident (Castleford, UK) (1992)**. As a result of a jet fire impacting the building, four employees in the control building were killed [25].

In 1995, American Petroleum Institute (API) published API Recommended Practice (RP) 752 *Management of Hazards Associated with Location of Process Plant Buildings*. The latest (4th) edition of this guidance (2024) gives the following guiding principles for the siting of permanent buildings in process plants:

a) Locate personnel away from process areas consistent with safe and effective operations;

b) Minimize the use of buildings/tents in close proximity to process areas;

c) Manage the occupancy of buildings/tents in close proximity to process areas, especially during periods of planned abnormal operation with increased risk including, but not limited to, unit start-up, testing, or planned shutdown operations;

d) Design, construct, install, modify and maintain buildings/tents to protect occupants from the hazards created by explosion, fire, and toxic material release; and

e) Manage the use of buildings/tents as an integral part of the design, construction, maintenance, and operation of a facility [26, p. 1].

In 2003, the CCPS published a book called *Guidelines for Facility Siting and Layout*. The latest (2nd) edition of this guidance (2018[a]) states:

> When structures are occupied or contain equipment critical for safe operations, they have to be adequately designed to reduce the risks to personnel and the critical equipment to protect them from the potential hazards, whether from fires, explosions, or toxic releases [27, p. 140].
>
> Separate control buildings from equipment and storage containing hazardous materials […]. Central and multi-unit control buildings should be located away from areas with potential fire and explosion damage […] [27, p. 153].
>
> Evaluate the control buildings for safe haven or blast-resistant construction or locate the control buildings with conventional construction in an area where safe haven or blast resistant construction is not needed. If the building is located in the hazardous area, toxic release and explosion impact analyses should be

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[a] The title of the 2nd edition (2018) of the book was changed to *Guidelines for Siting and Layout of Facilities*.

> performed with consequence impact studies or quantitative risk assessments […] [27, p. 153].

The API also created a recommended practice document in 2007, providing guidance on locating process plant portable buildings. The document was created in response to a CSB recommendation issued to API from the CSB's investigation of the 2005 BP Texas City refinery explosion, where 15 people were killed [28]. All of the victims in that incident were in or around portable trailers near the process area where the explosion occurred. The recommended practice, API RP 753 *Management of Hazards Associated with Location of Process Plant Portable Buildings* is based on the same guiding principles as those in API RP 752 (above) [29, p. 1].

Both the OSHA PSM standard, established in 1992, and the EPA RMP regulation, established in 1996, require facilities covered by them to conduct facility siting analyses:

- OSHA PSM: "The process hazard analysis shall address … facility siting"[a]
- EPA RMP: The hazard review or process hazard analysis shall address "stationary source siting, including the placement of processes, equipment, and buildings within the facility, and hazards posed by proximate stationary sources…"[b]

4.4.2 LACK OF FACILITY SITING ANALYSIS AT LOUISVILLE FACILITY

In 2012, the Louisville facility constructed the combined control room/laboratory that was in place at the time of the 2024 incident. The Louisville facility selected the design and location to increase communication between the lab technicians and the operators, while also keeping these personnel near the operating facility to minimize the distance operators had to walk between the control room/laboratory and process equipment. The control room/laboratory was only about 40 feet from Reactor 6 and was not designed to be blast-resistant.

The Louisville facility did not conduct a facility siting analysis to assess the safety of the control room/laboratory location. The Louisville facility was not covered by EPA RMP at the time of the control room/laboratory construction (after reducing its quantity of stored aqueous ammonia in 2007 below the EPA RMP threshold limit) and was not subject to a specific regulatory requirement to conduct the facility siting analysis.

During the November 12, 2024, incident, the Reactor 6 blast effects caused the control room to collapse (**Figure 37**). Six employees were inside the control room at the time of the incident Two of those employees were fatally injured when the control room collapsed on top of them.

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[a] 29 C.F.R. § 1910.119(e) *Process safety management of highly hazardous chemicals – Process Hazard Analysis*

[b] 40 C.F.R. § 68.50 and § 68.67 *Chemical Accident Prevention Provisions – Hazard Review and Process Hazard Analysis*

Figure 37. The collapsed control room at the Louisville facility after the incident. The red star in the left photo is approximately the camera perspective for the right photo, with the southeast corner of the control room indicated by blue highlighted lines. (Credit: Givaudan and Google Earth, annotated by CSB)

The CSB concludes that the Louisville facility's combined control room/laboratory was not located or constructed to avoid damage from the blast effects created by the rupture of Reactor 6. As a result, two employees were fatally injured when the control room collapsed on top of them. While the Louisville facility did not have a specific regulatory requirement to conduct a facility siting analysis, safely locating and protecting facilities, such as control rooms, from process hazards can help protect life and property during an incident.

The CSB concludes that had the Louisville facility conducted a facility siting study for the location of the combined control room/laboratory, it could have identified that the control room/laboratory needed to be designed, constructed, or located to protect occupants from hazards created by explosion, fire, or toxic material release, which could have prevented the fatal injuries to personnel on the day of the incident.

The CSB recommends that Givaudan contract a third party to conduct a facility siting study before constructing caramel coloring facility(ies) to help protect facility occupants and critical equipment from hazards created by explosion, fire, or toxic material release, using published industry guidance, such as that in the Center for Chemical Process Safety book, *Guidelines for Siting and Layout of Facilities*. (*2024-06-I-KY-R7*)

4.5 REGULATORY COVERAGE OF REACTIVE HAZARDS

4.5.1 BACKGROUND

In 1992, OSHA promulgated the PSM standard,[a] and in 1996 EPA promulgated its RMP rule[b] to manage chemical process safety and to help prevent major accidental releases. Together, these regulations require chemical facilities to manage process safety to protect workers, members of the public, the community, and the environment. Each regulation covers facilities that process certain chemicals exceeding certain threshold amounts. The OSHA PSM standard covers processes using flammable materials and individually listed

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[a] 29 CFR § 1910.119 - *Process Safety Management of Highly Hazardous Chemicals*

[b] 40 CFR § 68 - *Chemical Accident Prevention Provisions*

chemicals that present a range of hazards, and the EPA RMP rule identifies covered substances based on flammability and toxicity.

While these regulations help improve process safety for many chemical processing facilities in the United States, they have a critical coverage gap: neither standard adequately covers facilities processing chemicals with reactive hazards that could have catastrophic consequences. Significantly, while the caramel coloring sugar ingredients are capable of undergoing a highly hazardous chemical reaction (*Section 3*), the caramel coloring manufacturing process is not covered by either the OSHA PSM standard or EPA RMP rule. As such, the Louisville facility was not required to implement baseline process safety management system elements to manage the safety of its operations under these regulations. While portions of the Louisville facility were once covered by the EPA RMP rule due to the amount of aqueous ammonia stored at the site, the Louisville facility was no longer covered by the EPA RMP regulation after 2007, when it reduced its quantity of stored aqueous ammonia below the EPA RMP threshold limit.

The Louisville facility did not voluntarily adopt regulatory standards such as the OSHA PSM standard and the EPA RMP regulation or utilize the extensive process safety guidance published by industry groups, such as the CCPS. During the U.S. House of Representatives Committee on Education and Labor hearing on the 2005 BP Texas City disaster, then-CSB Chairperson Carolyn Merritt stated, “The problem with voluntary programs is not everyone volunteers” [30, p. 47]. This points to the need for regulators to require facilities that store or process chemicals with reactive hazards, including those resulting from self-reactive chemicals and combinations of chemicals and process-specific conditions, to implement safety management system elements that can prevent catastrophic incidents like the November 2024 incident.

Both OSHA and EPA currently use predefined chemical lists to identify the processes subject to coverage under the PSM standard and RMP rule. The CSB found in 2002 that OSHA and EPA did not adequately consider reactive chemical hazards when developing these chemical lists, and, as a result, many reactive chemicals and processes, including heating sugar ingredients inside vessels, are not covered by these regulations [31]. This regulatory coverage gap relating to reactive chemicals and their hazards (1) points to a weakness with relying on fixed chemical lists to determine regulatory coverage, (2) contributed to the 2024 incident at the Louisville facility, and (3) contributed to many other reactive chemical incidents over the past three decades (see *Section 4.5.2* below). OSHA and state occupational safety and health agencies have resorted to citing companies for safety-related violations under OSHA’s General Duty Clause following incidents involving reactive chemicals not covered under the PSM standard. This approach is not proactive and is ill-suited for accident prevention. Under the Kentucky Occupational Safety and Health (KY OSH) program, the Kentucky Education and Labor Cabinet cited the Louisville facility for violations of the commonwealth’s Obligations of Employers and Employees[a] (akin to the federal OSHA General Duty Clause) for a total of $7,000 in penalties related to the November 2024 incident.

4.5.2 CSB’S 2002 REACTIVE HAZARD STUDY

In 2002, the CSB published a major report, titled *Hazard Investigation: Improving Reactive Hazard Management,* after completing a study on chemical hazards in the chemical process industry in the United

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[a] *Kentucky Revised Statute 338.031 – Obligations of employers and employees*

States. In that study, the CSB analyzed 167 known reactive chemical incidents that occurred between 1980 and 2001. The CSB's objectives included:

- Determining the impact of reactive chemical incidents
- Examining how industry, OSHA, and EPA address reactive chemical hazards
- Developing recommendations for reducing the number and severity of reactive chemical incidents

In the report, the CSB concluded that

> … two elements are particularly relevant to reactive hazards–Process Safety Information (PSI; 29 C.F.R. § 1910.119(d)) and Process Hazard Analysis (PHA; 29 C.F.R. § 1910.119(e)). Two commonly cited causes of reactive incidents … are inadequate understanding of reactive chemistry or inadequate hazard evaluation … [31, pp. 55-56]
>
> … the [OSHA] PSM Standard has significant gaps in coverage of reactive hazards because it is based on a limited list of individual chemicals with inherently reactive properties. [31, p. 56]
>
> When developing the [EPA's Accidental Release Prevention] list of substances, EPA considered only the inherent characteristics of a chemical that indicate a severe threat due to exposure. Well-defined criteria were used for toxicity and flammability. However, because of the complexities of site-specific factors and process conditions, EPA was unable to determine any inherent characteristic as an indicator of reactivity. EPA concluded that there was "insufficient technical information for developing criteria for identifying reactive substances." Consequently, the January 1994 RMP list of 130 chemicals does not contain any substances listed due to reactive hazards. [31, p. 60]

In the 2002 report, the CSB recommended that OSHA:

> Amend the Process Safety Management Standard (PSM), 29 CFR 1910.119, to achieve more comprehensive control of reactive hazards that could have catastrophic consequences.[a]

The CSB also recommended that EPA:

> Revise the Accidental Release Prevention Requirements, 40 CFR 68, to explicitly cover catastrophic reactive hazards that have the potential to seriously impact the public, including those resulting from self-reactive chemicals and combinations of chemicals and process-specific conditions.

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[a] The CSB superseded the original recommendation language in its Optima Belle Investigation Report number 2021-02-I-WV, recommendation 2021-02-I-WV-R13 [18].

Since 2002, the CSB has repeatedly reiterated both of these recommendations in other CSB investigation reports on reactive chemical incidents. Neither OSHA nor EPA has implemented these recommendations, however, or improved the PSM standard or RMP rule to increase coverage of reactive chemicals.

The CSB has investigated 15 additional incidents since 2002 involving reactive chemicals that are not covered by the OSHA PSM standard and EPA RMP rule. Those incidents resulted in 31 fatalities and hundreds of injuries (**Table 1**).

Table 1. Incidents investigated by the CSB since September 2002 involving reactive chemicals that are not covered under OSHA's PSM standard or the EPA's RMP rule.

Date	Investigation Description	Chemical(s) Involved	Severity
October 13, 2002	First Chemical Corporation reactive explosion and fire	Mononitrotoluene	3 injured
April 12, 2004	MFG Chemical Inc. unintended decomposition reaction	Triallyl cyanurate	154 hospitalized
December 19, 2007	T2 Laboratories runaway reaction and explosion	Methylcyclopentadienyl Manganese Tricarbonyl, Methylcyclopentadiene, and Diglyme	4 fatalities 32 injured
August 28, 2008	Bayer CropScience, LP runaway decomposition	Methomyl	2 fatalities
April 17, 2013	West Fertilizer Company fire and explosion	Fertilizer Grade Ammonium Nitrate	15 fatalities More than 260 injured
August 28, 2016	Airgas nitrous oxide decomposition reaction and explosion	Nitrous Oxide	1 fatality
October 20, 2016	MGPI Processing Inc. chemical reaction and release	Sulfuric Acid and Sodium Hypochlorite	More than 140 required medical attention
May 24, 2017, and June 20, 2017	Midland Resource Recovery chemical reaction and explosions	Sodium Hypochlorite and Tertiary Butyl Mercaptan	2 fatalities 1 severely injured
May 3, 2019	AB Specialty Silicones chemical reaction, explosion, and fire	Andisil® XL 10 and TD 6/12 Blend	4 fatalities
August 27, 2020	Bio-Lab Lake Charles reaction, decomposition, and fire	Trichloroisocyanuric Acid	No reported injures
September 14, 2020	Bio-Lab Conyers reaction and decomposition	Trichloroisocyanuric Acid	9 required medical attention
December 8, 2020	Optima Belle chemical decomposition and explosion	Sodium Dichloroisocyanurate Dihydrate	1 fatality 3 required medical attention
September 9, 2024	Bio-Lab Conyers reaction, decomposition, and fire	Trichlorocyanuric Acid and Dichloroisocyanurate	Facility destroyed
November 12, 2024	Givaudan decomposition reaction and explosion	Sugar ingredients	2 fatalities 3 serious injuries

4.5.3 CONCLUSION

The CSB concludes that had the Louisville facility been required to implement the safety management system elements required under the OSHA PSM standard and the EPA RMP rule, including Process Hazard Analysis, Management of Change, and Process Safety Information (process knowledge management) compilation, the personnel involved in the Reactor 6 design at the Louisville facility would have had much more robust and reliable opportunities to become aware of the caramel coloring sugar ingredients' decomposition hazards, which could have led to the design of Reactor 6's emergency pressure relief system for the accelerated decomposition scenario, preventing the incident.

The CSB again reiterates its recommendations to OSHA and EPA to broaden the coverage of PSM and RMP, respectively, to achieve more comprehensive control of reactive hazards. (*2021-02-WV-R13* and *2001-01-R3*)

5 CONCLUSIONS

5.1 FINDINGS

Technical Analysis

1. On the day of the incident, the sugar ingredient of the Reactor 6 caramel coloring mixture underwent an uncontrolled (runaway) exothermic (heat-producing) decomposition reaction that produced high temperature and high pressure—from the generation and heating of non-condensable gases—that caused Reactor 6 to catastrophically rupture.

2. Operators followed the Product 484 batch instruction and implemented typical Product 484 manufacturing practices on the day of the incident. There were no abnormal materials, abnormal quantities of materials, or abnormal feed sequences that were causal to the incident.

3. When the Reactor 6 vent valve (pressure control valve) failed in the closed position 18 minutes before the Reactor 6 rupture, an important mechanism for controlling the reactor temperature by evaporating and venting water vapor was lost. As a result of the valve failure, the typically controlled exothermic sugar decomposition reaction accelerated.

4. The Reactor 6 vent valve failure could have resulted from a malfunction in any of the three control valve components: the valve, the actuator, or the positioner. However, there is insufficient evidence to determine why the Reactor 6 vent valve failed to function correctly during the 18 minutes before Reactor 6 ruptured. No mechanical deformities or obstructions were identified in the valve, the actuator appears to have been appropriately sized for the application but could not be tested due to damage sustained in the explosion, and the positioner was not recovered after the incident and could not be analyzed or tested.

5. Although the Reactor 6 cooling water system was activated 9 minutes before the incident in an attempt to reduce the Reactor 6 temperature, the cooling water system was unable to adequately remove the heat generated by the accelerating exothermic decomposition reaction. As a result of this inability to adequately remove heat from the reactor, the Reactor 6 temperature continued to rise, and the exothermic decomposition reaction continued to accelerate until Reactor 6 ruptured.

6. The Reactor 6 emergency pressure relief system, consisting of a rupture disc and pressure relief valve, did not show any signs of mechanical malfunction that would have prevented it from operating on the day of the incident.

7. The Reactor 6 emergency pressure relief system functioned as designed but was undersized for the accelerated sugar decomposition reaction that occurred on the day of the incident. As a result of the emergency pressure relief system's inadequate size, the gases and pressure generated by the accelerated decomposition reaction could not be adequately relieved from the reactor, and the reactor's internal pressure continued to rise from the formation and heating of the gases until Reactor 6 ruptured from the runaway reaction. To prevent the Reactor 6 rupture, the existing emergency pressure relief system (pressure relief valve with rupture disc) would have needed to be four times larger. Alternatively,

calculations and modeling software show that a 4-inch rupture disc alone should have provided the necessary relief capacity to prevent the rupture of Reactor 6.

Understanding Chemical Reaction Hazards

8. Further analysis of the 2012 Product 034 reactivity testing results and additional reactivity testing could have led D.D. Williamson to discover that the generation of high temperature and pressure in the 2012 testing was caused by the self-heating and decomposition of Product 034's sugar ingredient. This discovery could have led the company to realize that many of its caramel coloring products' sugar ingredients could have similar reactivity potential. This, in turn, could have led the company to implement equipment design changes that could have prevented the 2024 incident, including equipping Reactor 6 with an emergency pressure relief system specifically designed for the sugar decomposition reaction scenario. However, D.D. Williamson did not choose to conduct additional reactivity testing beyond the minimum that the EPA Consent Decree required.

9. There is no industry guidance specifically for the safe manufacturing of caramel coloring products. The development of such guidance detailing the known hazards of caramel color manufacturing and the need for appropriately sized emergency pressure relief systems to safely vent pressure and gases that could be produced by sugar ingredient decomposition reactions can help prevent future catastrophic vessel overpressure incidents.

10. Safety information communicated in sugar ingredient safety data sheets (SDSs) can vary significantly among suppliers. The SDS provided to Givaudan by the invert sugar manufacturer did not warn of the hazardous decomposition reaction potential of the invert sugar ingredient, while an SDS by a different manufacturer did warn of the decomposition hazard. Improved hazard information in sugar ingredient SDSs can help prevent future catastrophic sugar decomposition incidents.

Commitment to Managing Process Safety

11. After increasing the emergency pressure relief system sizes for Reactors 3 and 4 to safeguard against the pressures produced from the reaction identified in the 2012 reactivity testing of Product 034, D.D. Williamson did not clearly document this important safety improvement as a safeguard due to inadequacies in implementing the facility's MOC program. As a result, the Louisville facility had minimal written records to help future personnel understand the purpose and rationale for these relief system design changes. The lack of written records contributed to the Reactor 6 design team being unaware of both the 2012 Product 034 reactivity testing results and the differences in relief system sizes among the existing reactors and, in turn, ultimately contributed to the installation of an undersized relief system for Reactor 6.

12. After 2008, the Louisville facility never again completed another hazard analysis for its caramel coloring reactors. Had Louisville facility personnel continued to conduct hazard analyses, they should have updated the associated documentation to include the reactivity information discovered in 2012 regarding Product 034 and the related emergency pressure relief system size increases as safeguards. This documentation should have informed the Reactor 6 design team of the 2012 chemical reactivity testing results of Product 034 and the subsequent pressure relief design changes to Reactors 3 and 4,

which could have helped the team recognize that Reactor 6 needed a larger emergency pressure relief system.

13. The Louisville facility failed to follow key elements of its own safety management program, including management of change and hazard analyses. Had the Louisville facility fully implemented its written safety management system, it would have provided opportunities for facility personnel to be aware that there were reactive hazards present at the site. This, in turn, could have led to the realization that additional reactivity analyses and emergency pressure relief design evaluations were warranted, which could have prevented the incident.

14. The Louisville facility did not perform a PHA on the designs of Reactors 5 and 6 before their installation and operation. Conducting a hazard analysis on the Reactor 5 and 6 designs would have been a key opportunity for the Louisville facility to review previous hazard analyses, past facility change management documents, chemical reactivity testing results, and the planned safeguard designs for Reactors 5 and 6 to ensure all identified hazards were prevented or controlled. Since a PHA was not completed, a key opportunity was missed to identify that Reactor 6's emergency pressure relief system needed to be designed to relieve the gases/pressure generated from the chemical reaction of caramel coloring ingredients.

15. The lack of an "owner" of the Louisville facility's process safety policies contributed to the Louisville facility inconsistently conducting MOC reviews, action item implementation, and process hazard evaluations as part of the site's Hazard Identification and Risk Assessment program. The lack of strong company leadership on the implementation of these process safety policies directly contributed to personnel involved in the Reactor 5 and Reactor 6 design being unaware of the 2012 chemical reactivity testing results of Product 034 and the resulting Reactor 3 and 4 emergency pressure relief system sizing increases, and ultimately led to the installation of an undersized emergency pressure relief system for Reactor 6. For a safety management system to be successful, it must be overseen by competent person(s) who have the authority and knowledge to carry out the assigned duties. Implementing a robust process safety management system, such as through the framework detailed in the CCPS's *Guidelines for Risk Based Process Safety,* can help Givaudan improve the process safety management of its caramel coloring facilities and prevent future process safety incidents.

Safe Operating Limits

16. Had employees pulled the fire alarm to evacuate the facility at 2:54:04 p.m.—when the pressure safe operating limit was reached—personnel would have had about 3.5 minutes to evacuate the building before the Reactor 6 explosion occurred at 2:57:41 p.m.

17. While the Louisville facility had established pressure and temperature safe operating limits for its reactors, the Louisville facility operators were not familiar with the safe operating limit values due to inadequate training. As a result, operators and maintenance personnel continued troubleshooting the Reactor 6 abnormal operation on the day of the incident and did not take the prescribed action of evacuating the building when the safe operating limits were exceeded.

18. The Louisville facility did not adequately train its operators on the values of, purpose of, or required response to the established safe operating limits. The Louisville facility also did not establish other

indicators, such as alarms or other control room notifications, to alert operators that a safe operating limit had been exceeded.

19. Givaudan's safe operating limits program was not effective.

Facility Siting

20. The Louisville facility's combined control room/laboratory was not located or constructed to avoid damage from the blast effects created by the rupture of Reactor 6. As a result, two employees were fatally injured when the control room collapsed on top of them. While the Louisville facility did not have a specific regulatory requirement to conduct a facility siting analysis, safely locating and protecting facilities, such as control rooms, from process hazards can help protect life and property during an incident.
21. Had the Louisville facility conducted a facility siting study for the location of the combined control room/laboratory, it could have identified that the control room/laboratory needed to be designed, constructed, or located to protect occupants from hazards created by explosion, fire, or toxic material release, which could have prevented the fatal injuries to personnel on the day of the incident.

Regulatory Coverage of Reactive Hazards

22. Had the Louisville facility been required to implement the safety management system elements required under the OSHA PSM standard and the EPA RMP rule, including Process Hazard Analysis, Management of Change, and Process Safety Information (process knowledge management) compilation, the personnel involved in the Reactor 6 design at the Louisville facility would have had much more robust and reliable opportunities to become aware of the caramel coloring sugar ingredients' decomposition hazards, which could have led to the design of Reactor 6's emergency pressure relief system for the accelerated decomposition scenario, preventing the incident.

5.2 CAUSE

The CSB determined that the cause of the explosion was a high-pressure condition resulting from the accelerated decomposition of a sugar ingredient. The high pressure could not be adequately relieved through the undersized emergency pressure relief system. The emergency pressure relief system was undersized due to the facility management's fundamental lack of understanding of the chemical reaction hazards associated with sugar ingredients. To prevent the Reactor 6 rupture, the existing emergency pressure relief system (pressure relief valve with rupture disc) would have needed to be four times larger.

Contributing to the incident were serious deficiencies in the facility's implementation of its process safety policies, which contributed to a loss of institutional knowledge about caramel coloring manufacturing hazards after reactivity information regarding one of its products (Product 034) was discovered in 2012. The serious deficiencies in the facility's implementation of its process safety policies led to the installation of an undersized emergency pressure relief system for the reactor.

Contributing to the severity of the incident was the Louisville facility's failure to adequately train and to automatically alert personnel when safe operating limits were reached. As a result, facility personnel continued to troubleshoot while Reactor 6 was in an unsafe condition and did not evacuate the building. Also contributing to the severity of the incident was the lack of a facility siting analysis for the location of the control room, which was situated near the reactor and constructed without blast protection.

6 RECOMMENDATIONS

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:[a]

Previously Issued Recommendations Reiterated in This Report

6.1 U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

2001-01-H-R3 (from the 2002 CSB Reactive Hazard Study)

Revise the Accidental Release Prevention Requirements, 40 CFR 68, to explicitly cover catastrophic reactive hazards that have the potential to seriously impact the public, including those resulting from self-reactive chemicals and combinations of chemicals and process-specific conditions. Take into account the recommendations of this report to OSHA on reactive hazard coverage. Seek congressional authority if necessary to amend the regulation.

6.2 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

2021-02-I-WV-R13 (from the 2002 CSB Reactive Hazard Study, as superseded in the Optima Belle investigation report)

Amend the Process Safety Management Standard (PSM), 29 CFR 1910.119, to achieve more comprehensive control of reactive hazards that could have catastrophic consequences.

- Broaden the application to cover reactive hazards resulting from process-specific conditions and combinations of chemicals. Additionally, broaden coverage of hazards from self-reactive chemicals. In expanding PSM coverage, use objective criteria. Consider criteria such as the North American Industry Classification System (NAICS), a reactive hazard classification system (e.g., based on heat of reaction or hazardous gas evolution), incident history, or catastrophic potential.
- In the compilation of process safety information, require that multiple sources of information be sufficiently consulted to understand and control potential reactive hazards. Useful sources include but are not limited to:
  - Literature surveys (e.g., Bretherick's Handbook of Reactive Chemical Hazards, Sax's Dangerous Properties of Industrial Materials, CAS SciFinder).

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[a] Givaudan has indicated that the company is considering rebuilding the caramel coloring production facility in a new location. The CSB has not made a recommendation to Givaudan regarding the siting of any such new facility, but the CSB is concerned about the substantial damage that the explosion at the Louisville facility caused to homes in the surrounding neighborhood and the significant risk that was posed to the community by the incident. The CSB urges Givaudan to ensure that any new production facility will not be located in close proximity to a residential area in order to help prevent another community from being put at serious risk.

  - Information developed from computerized tools (e.g., ASTM's CHETAH, CCPS's Chemical Reactivity Worksheet).
  - Chemical property data in PubChem and the REACH (Registration, Evaluation, and Authorization of Chemicals) dossiers maintained by the European Chemicals Agency (ECHA).
  - Chemical reactivity test data produced by employers or obtained from other sources following established standards such as:
    - ASTM E537-20, Standard Test Method for Chemicals by Differential Scanning Calorimetry;
    - ASTM E1981-22, Standard Guide for Assessing Thermal Stability of Materials by Methods of Accelerating Rate Calorimetry;
    - ASTM E2550-21, Standard Test Method for Thermal Stability by Thermogravity; and
    - ASTM E1231-19, Standard Practice for Calculation of Hazard Potential Figures of Merit for Thermally Unstable Materials.
  - Relevant incident data from the plant, the corporation, industry, and government.
- Augment the process hazard analysis (PHA) element to explicitly require an evaluation of reactive hazards. In revising this element, evaluate the need to consider relevant factors, such as:
    - Rate and quantity of heat or gas generated.
    - Maximum operating temperature to avoid a runaway reaction from decomposition.
    - Time to Maximum Rate under Adiabatic Conditions (TMR_{ad}).
    - Thermal stability of reactants, reaction mixtures, byproducts, waste streams, and products.
    - Effect of variables such as charging rates, catalyst addition, and possible contaminants.
    - Understanding the consequences of runaway reactions or hazardous gas evolution.

New Recommendations

6.3 GIVAUDAN FACILITIES THAT MANUFACTURE CARAMEL COLORING PRODUCTS

2024-06-I-KY-R1

Contract a third party to analyze the reactivity of the sugar ingredients in the caramel coloring product manufacturing process by, at a minimum:

a. Conducting calorimetry testing on at least one representative recipe for all caramel coloring product types to determine their temperature and pressure behavior upon heating.

b. Testing the composition of any produced non-condensable gases.

Maintain this information for use during future equipment design efforts and hazard analyses.

2024-06-I-KY-R2

Contract a third party to conduct a hazard analysis of each caramel coloring facility. Require this analysis to address reactivity hazards and include a review of the reactivity data obtained from implementing CSB

Recommendation 2024-06-I-KY-R1. Implement the recommendations issued by the third party as a result of the hazard analyses.

2024-06-I-KY-R3

Contract a third party to develop a process safety management system to be used at each caramel coloring facility. This third party shall:

a. Ensure the process safety management system is in alignment with current industry guidance such as the CCPS's *Guidelines for Risk Based Process Safety*.

b. Ensure that the process safety management system requires hazard reviews/analyses to be conducted at prescribed intervals and include:

   (1) the review/incorporation of reactivity data from CSB Recommendation 2024-06-I-KY-R1 and any additional reactivity data obtained during the course of operating any caramel coloring facility,
   (2) the review/analysis of any process changes that could affect relief system designs, and
   (3) the review/updating of the facility siting study from CSB Recommendation 2024-06-I-KY-R7, as appropriate.

2024-06-I-KY-R4

At each caramel coloring facility, hire a new or identify a current employee who is competent in process safety management concepts. Establish this employee's job duties to specifically include overseeing the caramel coloring facility's process safety management system established in 2024-06-I-KY-R3, its implementation, and personnel training on the system's elements.

2024-06-I-KY-R5

For each caramel coloring facility, contract a third party to design adequate emergency pressure relief systems for the vessels involved in caramel coloring manufacturing. Ensure the third party reviews/incorporates all reactivity data obtained from the testing required by CSB Recommendation 2024-06-I-KY-R1 when designing the emergency pressure relief systems. Document and maintain each vessel's relief system design basis for the service life of the vessel.

2024-06-I-KY-R6

For each caramel coloring facility, establish automatic alerts, such as alarms or control screen indications, to notify operators when a safe operating limit has been reached. Follow industry guidance, such as the guidance presented in the Center for Chemical Process Safety Book *Guidelines for Engineering Design for Process Safety (2nd Edition)*, Chapter 5 *General Design*. Provide initial and refresher training for operations personnel on the established safe operating limits including the actions to take if these limits are exceeded.

2024-06-I-KY-R7

Contract a third party to conduct a facility siting study before constructing caramel coloring facility(ies) to help protect facility occupants and critical equipment from hazards created by explosion, fire, or toxic material release, using published industry guidance, such as that in the Center for Chemical Process Safety book, *Guidelines for Siting and Layout of Facilities*.

6.4 GIVAUDAN - CORPORATE

2024-06-I-KY-R8

Create and fill a corporate senior leadership position responsible for overseeing process safety at all Givaudan caramel coloring facilities or identify a current senior leader who is competent in process safety management concepts to fill this role. Establish this senior leader's job duties to oversee the process safety management system implementation at all Givaudan caramel coloring facilities. Assign this individual to develop corporate-level process safety management system policies to ensure consistent development and implementation of process safety management systems at all Givaudan caramel coloring facilities. One of the policies will address training operations personnel on defined safe operating limits and actions to take if those limits are exceeded.

6.5 INTERNATIONAL TECHNICAL CARAMEL ASSOCIATION

2024-06-I-KY-R9

Publish a technical safety bulletin for caramel coloring manufacturing that encourages caramel color manufacturers to ensure known hazards, including sugar ingredient decomposition, are addressed. Emphasize the importance of obtaining information on calorimetric properties of sugar ingredients and ensuring appropriately sized emergency pressure relief systems to safely vent pressure and gases that could be produced by sugar ingredient decomposition reactions, as well as other overpressure scenarios identified in hazard analyses. Refer caramel color manufacturers to the CSB's investigation report for additional details. Recommend in the technical safety bulletin that caramel coloring manufacturers implement, as appropriate, process safety management systems that are in alignment with local requirements and chemical industry good practice guidance, such as the Center for Chemical Process Safety *Guidelines for Risk Based Process Safety, Essential Practices for Managing Chemical Reactivity Hazards*, and *Guidelines for Implementing Process Safety Management*.

2024-06-I-KY-R10

Alert association members that manufacture caramel coloring of the November 12, 2024, Givaudan incident and its causes, including but not limited to the sugar ingredient decomposition reaction that led to Reactor 6's rupture.

6.6 INTERNATIONAL MOLASSES CORPORATION LTD.

2024-06-I-KY-R11

Update all invert sugar safety data sheets to include: the decomposition temperature, the consequences of exceeding that temperature, and the decomposition products produced (for example, carbon dioxide).

6.7 CORN REFINERS ASSOCIATION

2024-06-I-KY-R12

Alert association members who manufacture corn syrup of the November 12, 2024, Givaudan incident and its causes, including but not limited to the sugar ingredient decomposition reaction that led to Reactor 6's rupture. Request that they update their corn syrup safety data sheets to include: the decomposition temperature, the consequences of exceeding that temperature, and the decomposition products produced (for example, carbon dioxide).

7 KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. Chemical facilities should analyze any event in which their chemicals or processes produce unanticipated temperature or pressure changes. Such events could indicate that the chemicals underwent a chemical reaction that must be understood to allow for the proper and safe design of equipment. Comprehensive reactivity testing (for example, calorimetry testing) on ingredients and final products can provide important information on temperature and pressure behavior during chemical reactions, which is essential information when sizing emergency pressure relief systems to protect equipment, workers, and communities from reactive hazards.

2. Safety data sheet (SDS) chemical hazard information can vary substantially between suppliers. End users should not rely solely on hazard information contained in the SDS when using the chemical at elevated temperatures or pressures, or with other chemicals with which the chemical could react. Additional hazard analyses may be needed to prevent process safety incidents. Companies should seek additional publicly available information, or obtain additional information through testing, to supplement information contained in a material's SDS.

3. Hazard analyses and effective change management processes are critical aspects of a robust process safety management system. Additionally, they are essential tools to document institutional knowledge of identified hazards and their safeguards, allowing this important information to be communicated to new personnel who were not at the site when the hazards were discovered and the safeguards were established.

4. Companies should ensure they are following industry guidance for revalidation timelines of hazard analyses and have competent personnel leading and contributing to the discussions. If companies do not have adequate personnel, outside experts should be hired to assist in identifying hazards and safeguards.

5. Companies should set, define, and train all employees on safe operating limits to ensure personnel are able to identify that the equipment has reached an unsafe condition, troubleshooting efforts need to end, and predetermined actions must be taken to protect employees. Visual and audible alarms should be utilized to alert personnel that the safe limits were exceeded, and the established response steps should be initiated.

6. When buildings are occupied by personnel or contain equipment critical for safe operations, they must be adequately designed or located to protect from fires, explosions, or toxic releases. Companies should conduct facility siting analyses of normally occupied spaces, such as control rooms, and make design changes as appropriate, to protect people and critical equipment from identified process hazards.

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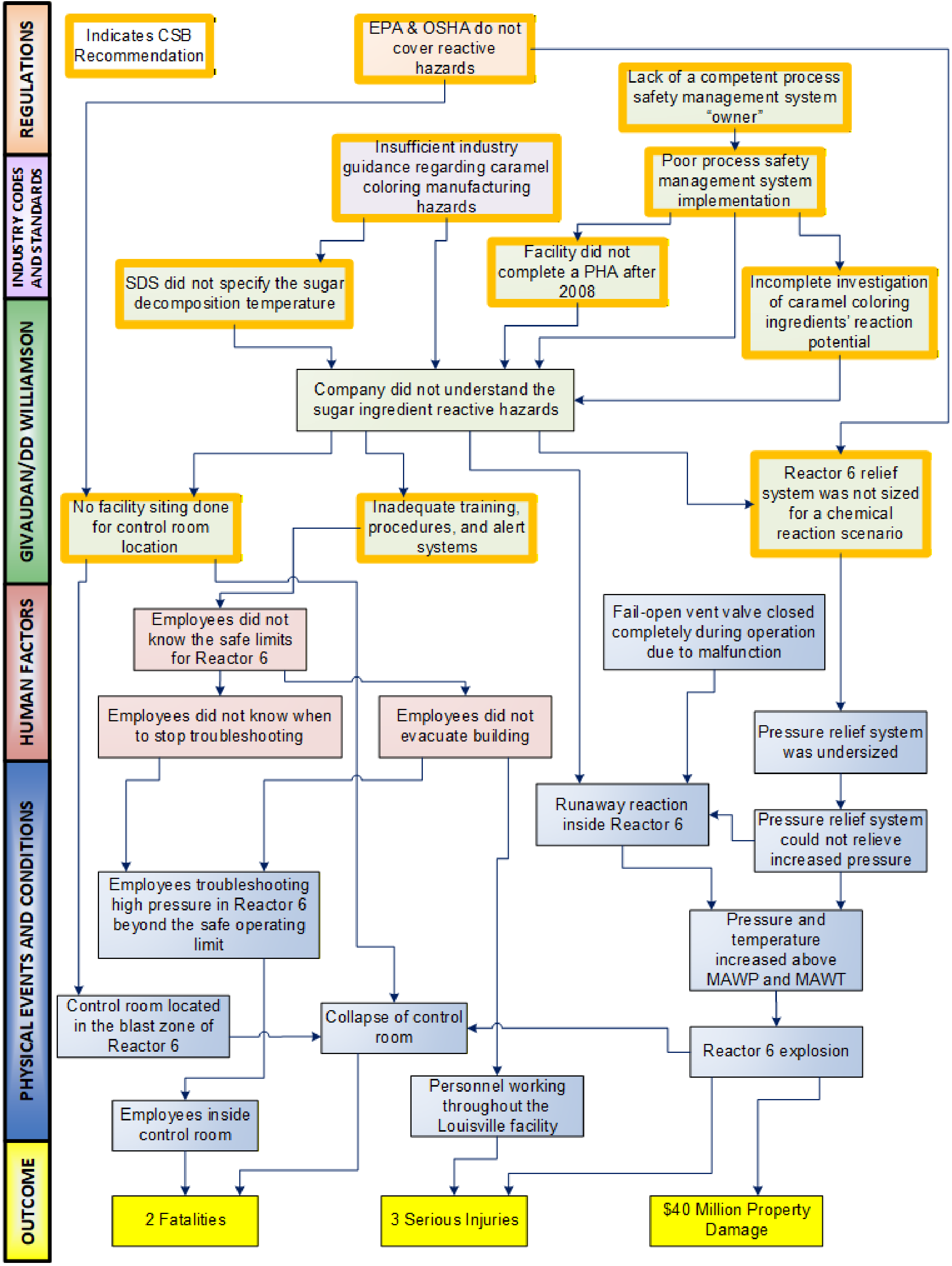
APPENDIX A—SIMPLIFIED CAUSAL ANALYSIS (ACCIMAP)



APPENDIX B—INCIDENT TIMELINE

Date	Time	Event
4/11/2003	2:10 a.m.	Previous fatal incident at D.D. Williamson site. A vessel explosion fatally injured one operator, released 26,000 pounds of aqueous ammonia, and forced the evacuation of 26 residents and the shelter-in-place of 1,500 people. The CSB investigated this incident.
3/2004		CSB issued recommendation to D.D. Williamson to "implement a hazard evaluation procedure to determine the potential for catastrophic incidents and necessary safeguards."
6/2006		Establishment of D.D. Williamson Management of Change (MOC) Policy.
2007		EPA and D.D. Williamson entered into negotiations regarding a consent decree as mandated by EPA after the April 11, 2003 explosion.
10/15/2007		D.D. Williamson reduced its amount of aqueous ammonia stored on site below the EPA RMP threshold limit, and as a result was no longer covered by the EPA RMP regulation.
2/21/2008		D.D. Williamson conducted HAZOP on equipment, including reactors, under the direction of a consultant. The HAZOP included a recommendation to "investigate the heat of reaction between ammonium bisulfite and ammonia" to determine how this may impact existing equipment design.
2008		D.D. Williamson facility in Modesto, CA, closes. Reactors 5 and 6 are transported to Louisville and stored for future capital improvement project.
8/2009		The CSB marked recommendations from the 2003 incident as "Closed – Acceptable Action"
7/10/2009		D.D. Williamson and EPA signed consent decree, requiring D.D. Williamson to hire an independent third-party engineering consultant to conduct a process hazard evaluation, operating procedures analysis, facility design analysis, maintenance operations analysis, and emergency response plan analysis.
1/27/2012		D.D. Williamson issued Product 484 batch instruction.
2012		Control room was relocated and combined with the laboratory within the Louisville facility.
10/15/2012		D.D. Williamson conducts reactivity testing recommended in 2008 HAZOP. Testing shows Product 034 ingredients experience a self-sustained temperature rise (exotherm), as well as a significant pressure rise due to the formation of non-condensable gases.
11/30/2012		Engineering consultant conducted relief sizing analysis utilizing the reactivity testing data for Product 034 and recommended D.D. Williamson to increase the pressure relief valve size for all reactors intended to produce Product 034 from an orifice area of 4.186 square-inches to 10.304 square-inches (Reactors 3 and 4).
2013		D.D. Williamson installed the increased orifice area (10.304 square inches) pressure relief valve on Reactors 3 and 4.
10/19/2015		D.D. Williamson completed EPA Consent Decree items, stating "All recommendations identified in the Final Work Plan were implemented and completed by D.D. Williamson as of September 17, 2013."
4/2017		Departure of engineering manager who led 2012 reactivity tests from D.D. Williamson.
By 2021		D.D. Williamson begins manufacturing Product 034 in Reactor 2; no management of change conducted for this procedural change.
09/2020		New plant engineer begins working at D.D. Williamson and is put in charge of Reactor 5 and 6 design project.
4/14/2021		New plant engineer ordered pressure relief valves with an orifice area of 4.186 square inches for Reactors 5 and 6.
08/2021		Installation of Reactors 5 and 6.
10/19/2021		MOC completed for Reactors 5 and 6. No PHA conducted.
12/19/2021		Givaudan Sense Colour acquired D.D. Williamson.
12/28/2021		Approximate first batch prepared in Reactor 6.
12/29/2021		Pre-Startup Safety Review completed for Reactors 5 and 6.
11/12/2024	10:22 a.m.	Day-of-incident batch of Product 484 started in Reactor 6. Normal operations were observed.

11/12/2024	11:18 a.m.	Reactor 6 pressure set point was changed to 12 psig per the batch instruction. The vent valve closed to increase the pressure within Reactor 6.
11/12/2024	2:24 p.m.	The pressure within Reactor 6 hit 12 psig pressure set point. The vent valve modulated to maintain pressure within Reactor 6.
11/12/2024	2:39 p.m.	The vent valve failed in the closed position and pressure increased above the 12 psig set point.
11/12/2024	2:47 p.m.	The temperature within the vessel increased past the 300°F set point. The valve supplying steam to the Reactor 6 coils was shut.
11/12/2024	2:48 p.m.	The valve supplying cooling water to the reactor was opened in an attempt to cool the reactor.
11/12/2024	2:52 p.m.	Reactor 6 icon turned red on the control room computer screen, indicating adverse process conditions, which was acknowledged by the operator monitoring the computer.
11/12/2024	2:54 p.m.	Maintenance technician attempts to manually open the vent valve using a crescent wrench.
11/12/2024	2:54 p.m.	The pressure relief device opened, temporarily reducing the pressure within the reactor, before it began to rise again.
11/12/2024	2:55 p.m.	Reactor 6 pressure exceeded its MAWP and safe limit of 75 psig. Employees remained in the control room, troubleshooting.
11/12/2024	2:56 p.m.	Reactor 6 temperature exceeded its MAWT and safe limit of 355°F. Employees remained in the control room, troubleshooting.
11/12/2024	2:57:41 p.m.	Catastrophic failure of Reactor 6. Maximum recorded pressure of 237 psig. Maximum recorded temperature of 355°F. Maintenance technician recovered from control room rubble and transported to the hospital, where he died from his injuries. Explosion debris launched offsite into neighborhood.
11/12/2024	3:17 p.m.	Residents within a 1-mile radius are asked to shelter in place. Two elementary schools and one K-12 school were ordered to shelter in place, and dismissal at the schools was delayed.
11/12/2024	4:32 p.m.	One-mile shelter-in-place was lifted.
11/13/2024	1:00 a.m.	Employee was identified as missing, and his body was retrieved from the collapsed building.

APPENDIX C—REACTIVITY TESTING RESULTS

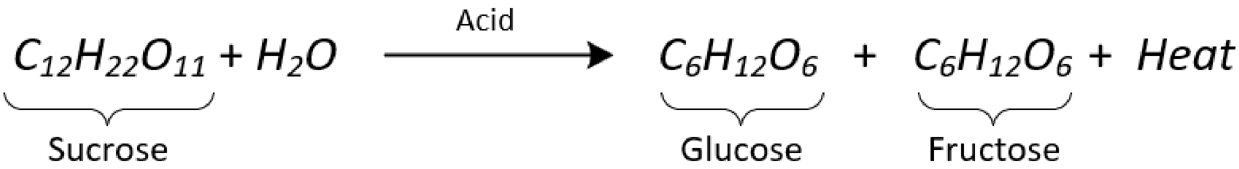
This appendix is located on the Givaudan investigation page at www.csb.gov.

APPENDIX D—CARAMEL REACTION MECHANISM

The CSB conducted a literature review [32] [33] [34] [35] [36] and worked with expert consultants to determine the reaction mechanisms that occur during the production of caramel coloring, including those capable of generating the high temperature and pressure conditions in Reactor 6 on the day of the incident. A simplified presentation of the likely chemical reaction sequence is detailed below, highlighting the dominant sequence of reactions leading to the incident. The full reaction chemistry is more complex, involving multiple parallel and competing reactions.

Sucrose Inversion

Caramel coloring is produced from a sugar-containing starting material through a series of chemical reactions. The initial reaction, commonly called sugar inversion, is the acid-catalyzed hydrolysis[a] of the disaccharide[b] sucrose into its component monosaccharides,[c] glucose and fructose.[d]



$$\underbrace{C_{12}H_{22}O_{11}}_{\text{Sucrose}} + H_2O \xrightarrow{\text{Acid}} \underbrace{C_6H_{12}O_6}_{\text{Glucose}} + \underbrace{C_6H_{12}O_6}_{\text{Fructose}} + \text{Heat}$$

*Glucose and Fructose have the same molecular formula but different molecular structures

On the day of the incident, the Louisville facility utilized a "medium invert syrup" as its base starting material for the caramel coloring production process, which the facility mixed with phosphoric acid, sodium hydroxide, water, and an antifoam additive. A medium invert syrup is a viscous liquid mixture in which approximately 50 percent of the sucrose has been hydrolyzed to glucose and fructose monosaccharides.

HMF Formation

In the second step of the reaction, fructose undergoes an acid-catalyzed dehydration[e] process to form the intermediate material, 5-hydroxymethylfurfural (HMF). The formation of HMF can occur rapidly when an acidified sucrose solution is subjected to high temperatures and pressures [33].

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[a] Hydrolysis is a chemical reaction in which a molecule of water breaks a chemical bond.

[b] A disaccharide is a sugar formed from two monosaccharides.

[c] A monosaccharide is a simple sugar molecule, like glucose or fructose, that cannot be hydrolyzed to form a simpler sugar. Monosaccharides are the building blocks of more complex sugars such as disaccharides and polysaccharides.

[d] Glucose and fructose both have the same molecular formula, $C_6H_{12}O_6$, but have different molecular structures.

[e] Dehydration is a chemical reaction that involves the loss of water from the reacting molecule.

$$C_6H_{12}O_6 + Heat \xrightarrow{\text{Acid}} \underbrace{C_6H_6O_3}_{\text{HMF}} + 3\,H_2O$$

Once HMF has been formed, several subsequent reactions can take place (**Figure 38**) depending upon the reaction conditions, such as temperature and pH. Each of these subsequent reactions is discussed below.

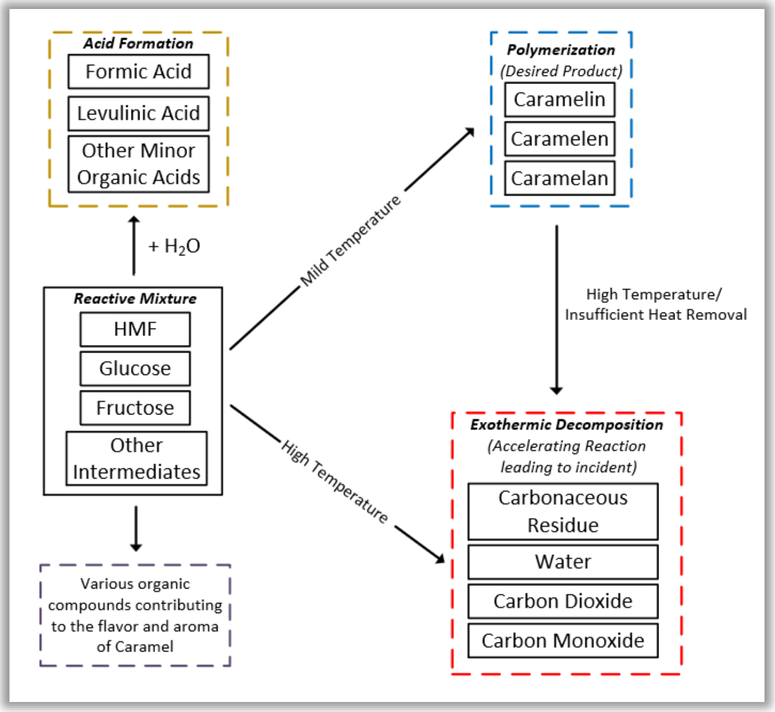

Figure 38. Simplified illustration of the possible reaction pathways. (Credit: CSB)

Acid Formation Reaction

Under normal process conditions, some HMF will react with water, generating organic acids,[a] primarily Levulinic acid and Formic acid. If these acids are not neutralized, they can increase the rate of sucrose inversion and the generation of HMF from fructose [32].

$$\underbrace{C_6H_6O_3}_{\text{HMF}} + 2\,H_2O \longrightarrow \underbrace{CH_2O_2}_{\text{Formic Acid}} + \underbrace{C_5H_8O_3}_{\text{Levulinic Acid}} + Heat$$

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[a] Organic acids are organic compounds with acidic properties.

Polymerization Reaction

Polymerization of HMF into caramelans, caramelens, and caramelins is the intended reaction to produce caramel coloring. The desired caramelization reaction is best achieved when the pH is less than 5 but not so low as to increase the generation of undesired byproducts. Due to the above acid formation reaction that produces Formic acid and Levulinic acid, it is necessary to control the pH with the addition of a base. At the Louisville facility, sodium hydroxide was used to control the pH during the caramel coloring manufacturing process.

$$\underbrace{nC_6H_6O_3}_{\text{HMF}} \longrightarrow \underbrace{C_{24}H_{36}O_{18}}_{\text{Caramelan}} + Heat \longrightarrow \underbrace{C_{36}H_{50}O_{25}}_{\text{Caramelen}} + Heat \longrightarrow \underbrace{C_{125}H_{188}O_{80}}_{\text{Caramelin}} + Heat$$

Exothermic Decomposition

HMF can undergo exothermic decomposition, resulting in the formation of polymeric carbonaceous residue (charring), water, carbon dioxide, and carbon monoxide. This reaction normally occurs, in a controlled manner, during the caramel color manufacturing process.[a] High process temperatures can accelerate this reaction and cause it to become uncontrolled [37].

$$\underbrace{nC_6H_6O_3}_{\text{HMF}} \longrightarrow x\,\underbrace{[C_y]}_{\substack{\text{Carbonaceous}\\ \text{residue}}} + z\,H_2O + w\,\underbrace{CO_2}_{\substack{\text{Carbon}\\ \text{Dioxide}}} + v\,\underbrace{CO}_{\substack{\text{Carbon}\\ \text{Monoxide}}} + Heat$$

The decomposition of HMF generates non-condensable gases (primarily carbon dioxide) and heat, which will contribute to the pressure rise in a closed vessel. Excess heat and inadequate temperature control will also result in parallel, simultaneous decomposition reactions involving the sugars, caramel polymers, and the formed intermediates. These decomposition reactions became uncontrolled (ran away) on November 12, 2024, to cause the Givaudan incident that is the subject of this report.

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[a] Process data shows that carbon dioxide was generated during the normal caramel color manufacturing process at the Louisville facility.

APPENDIX E—DESCRIPTION OF SURROUNDING AREA

Figure 39 shows the census blocks in the area surrounding the Givaudan facility. The census information for the blocks shown in **Figure 39** is presented in **Table 2**.[a]

Figure 39. Census blocks within approximately 1-mile distance from the Givaudan facility. (Credit: Census Reporter, annotated by CSB)

Table 2. Tabulation of demographic data for the populations within the census blocks and tracts shown in **Figure 39**.

Tract Number	Population	Median Age	Race and Ethnicity		Per Capita Income	% Persons Below Poverty Line	Number of Housing Units	Types of Structures	
1	3,790	36.5	86.0%	White	$ 46,867	9.0%	2,302	39%	Single Unit
			3.0%	Black				61%	Multi-Unit
			0.0%	Native				0%	Mobile Home
			1.0%	Asian				0%	Boat, RV, van, etc.
			0.0%	Islander					
			0.0%	Other					
			4.0%	Two+					
			5.0%	Hispanic					

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[a] This information was compiled using the 2023 U.S. Census Bureau American Community Survey 5-year estimate data as presented by Census Reporter [6].

2	2,369	33.2	81.0%	White	$ 69,367	11.5%	1,534	27%	Single Unit
			11.0%	Black				73%	Multi-Unit
			0.0%	Native				0%	Mobile Home
			4.0%	Asian				0%	Boat, RV, van, etc.
			0.0%	Islander					
			0.0%	Other					
			2.0%	Two+					
			2.0%	Hispanic					
3	2,511	35.6	79%	White	$ 42,152	15.0%	1,480	43%	Single Unit
			3%	Black				57%	Multi-Unit
			0%	Native				0%	Mobile Home
			4%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			2%	Two+					
			12%	Hispanic					
4	1,926	39.8	61%	White	$ 42,597	23.5%	1,330	28%	Single Unit
			25%	Black				72%	Multi-Unit
			0%	Native				0%	Mobile Home
			5%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			2%	Two+					
			6%	Hispanic					
5	1,804	42.3	92%	White	$ 57,699	4.6%	971	55%	Single Unit
			5%	Black				42%	Multi-Unit
			0%	Native				2%	Mobile Home
			1%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			2%	Two+					
			0%	Hispanic					
6	1,619	38.7	77%	White	$ 60,450	7.8%	1,047	34%	Single Unit
			14%	Black				66%	Multi-Unit
			0%	Native				0%	Mobile Home
			6%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			3%	Two+					
			1%	Hispanic					
7	3,554	40.9	56%	White	$ 42,868	12.9%	2,450	33%	Single Unit
			28%	Black				67%	Multi-Unit
			0%	Native				0%	Mobile Home
			8%	Asian				0%	Boat, RV, van, etc.
			0%	Islander					
			0%	Other					
			3%	Two+					
			6%	Hispanic					

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